AMRA MS 65-07

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PROCEEDINGS OF ADVANCED PLANNING BRIEFING FOR INDUSTRY

PART I

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U. S. ARMY MATERIALS RESEARCH AGENCY
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PROCEEDINGS OF ADVANCED PLANNING BRIEFING FOR INDUSTRY

PART I

UNITED STATES ARMY MATERIALS RESEARCH AGENCY

5-6-7 October 1965

Boston, Massachusetts

PREFACE

The advanced planning briefing of the U. S. Army Materials Research Agency (AMRA) was held three successive days, October 5, 6, and 7 1965, to present to representatives of industry, research institutes, and universities a broad view of future problems in the Army in the field of materials research that relates to military requirements. Through the cooperation of other segments of the Army, a sample insight into future Army systems requiring new or improved materials was included in the briefing. In the time allotted, AMRA chose to present a substantial cross section of the problem areas in materials research but could not cover all areas that will require attention in the next several years.

The Proceedings are issued in two parts. Part I contains all of the unclassified presentations and Part II covers the classified segments of the briefing.

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CHAPTER I

OPENING REMARKS

The Chairman of the Briefing, Mr. Norman L. Reed, Associate Director for Plans, U. S. Army Materials Research Agency (AMRA), called the assembly to order and announced the procedures for the sessions. He noted that the choice of the New England Telephone and Telegraph Company Headquarters Building in downtown Boston, Massachusetts, with its security-cleared facility, was exceptionally fortunate, not only for convenience to hotels and restaurants but, additionally, because of no time-loss for traveling to and from Watertown, thus allowing a greater portion of the day to be devoted to the business at hand.

The Greeting was by Mr. Victor P. McDavitt, the General Defense Coordinator for New England Telephone. To those assembled and on behalf of this company, he dwelled briefly on the history and background of the company and the communications industry, noting the need for planning in materials research as well as in defense communications in which the company was rather continuously engaged. He wished us success in the worthy undertaking of imparting future plans to the nationwide attendees.

WELCOMING ADDRESS

Lt. Colonel Joseph E. Black
Commanding Officer
U. S. Army Materials Research Agency

Welcome to the Army Materials Research Agency's Advanced Planning Briefing for Industry. The word "Industry" perhaps is not the most appropriate since the attendees are from universities, research institutes, as well as the research and development segments of the nation's industry. I trust this word hasn't bothered you so far. The Department of Defense uses it as a generic term.

As an independent research laboratory of the Army Materiel Command, we function in the field of materials research, accomplishing a substantial amount of research with our own staff; contracting with external sources for research effort in specific fields; and additionally have a function to coordinate the Materials Research Program of the Army Materiel Command.

Over a great many years we have worked closely with the scientific community of the nation in fields of mutual interest; we will continue to do so. The exchanges that we have with you occur in many ways: during the visits of your staff to AMRA; when we travel to your base of operations; during the technical sessions of the national professional societies; at our annual Sagamore Materials Research Conferences, and in many other ways. All these help to keep pace with mutual needs.

I believe I am correct when I state that the vast majority of these meetings have been very helpful and necessary exchanges; they must be continued.

Probably most meetings have been focused on a specific field of endeavor and thus reasonably narrow during any one exchange.

We doubt that many of you have had an in-depth look at the Army's goals of the next several years and of the requirements for materials that accompany the new Army systems. All attendees here have been rigidly screened so that we can, in this Advanced Planning Briefing, talk about future warfare concepts, about Army systems for these concepts; and then, as the day progresses, we will place in front of you the thinking that our staff has generated in many of the materials research fields.

We sincerely hope that we will inspire in today's participants and, through you, in the groups you represent, a knowledge and insight of the requirements for materials that will be needed before the design and creation of new Army systems can be undertaken or existing systems upgraded very appreciably in performance.

It is the aim of this exchange, and any future exchanges that may result from this briefing, that they be mutually fruitful. We will point out our problems, and we would like to be informed of the potential of some of the materials already available because of your efforts.

We have had your fine cooperation in related matters over a long period of time. We know it is most essential in the future and thus this formal classified briefing will soon get underway.

It is our deep conviction that by "taking you into the family", as we are doing this morning, you will come forth with ideas for research that will be most helpful. Ideally, the flow of information and ideas must be both to you and from you. We thus welcome the opportunity of presenting this Army story to you.

During the discussion period or after you return to your activity, we most cordially welcome your thoughts and suggestions concerning new materials or research thereon. I and my staff will be here throughout the day, and I hope by discussion we can lead the way to the pursuit of meaningful activities.

May you enjoy the busy day we have scheduled for you.

KEYNOTE ADDRESS

Dr. J. L. Martin
Technical Director
U. S. Army Materials Research Agency

The Materials Research program of the Army is quite broad; it includes research, both basic and applied, as well as effort in exploratory and advanced development. At the U. S. Army Materials Research Agency the program in R&D together with the materials engineering activities consistently contribute to the Army's needs. Occasionally we complete the gamut from research

to hardware. In the area of armor and that of components for atomic ammunition starting with the concept study, we undertake the feasibility and engineering development aspects as well as engineering tests carrying the item right through to pre-production. Additionally, the responsibility of producing and continually updating standards and specifications covering a wide variety of materials is assigned to us. Having all these facets of the materials research program within one Agency has the distinct advantages of "coupling", within a minimum time frame, materials research to application and use.

As you are learning today, we have the responsibility to bring to the interested segments of industry the results of research, to work with you in exploring Army needs, and to request your help in the ever-growing and increasingly complicated area of materials for Army systems.

I would like to talk to you about our current status and where we believe we should be in the near future to keep pace with the Army's needs. To do this I have chosen to talk about Manpower; Facilities; Equipment; Requirements - Knowledge of What is Needed; Dissemination of Information; Industry's Role in Fulfilling the Army's Requirements.

Manpower

A major segment of the Army's materials research effort is conducted by AMRA, located in Watertown, Massachusetts, adjacent to Boston and surrounded by the very extensive scientific and technological effort of the community. Because of this we are admirably located to attract and retain the variety and number of personnel that are needed for our mission of accomplishing research and coordinating the other portions of the materials research effort of the Army.

We have been able to maintain an atmosphere for research and development that is favorably accepted. In many instances it approaches the universities in freedom to pursue avenues of basic research that are uncovered as our theoreticians or experimentalists proceed with their programs; both of these research types have colleagues in the area engaged in related work. The discussions and presentations of our scientists at colloquia are evidence of the community of associated interest in which they work and dwell. The scientists and engineers involved in materials engineering and technological phases of the program are knowledgeable not only of their own work but additionally, because they visit the operations of others in the same field, are conscious of the latest endeavors both nationally and internationally.

Those to whom we turn for standards and specifications find that by "living" with the research scientists and engineers they are continually alert to the latest information, physical characteristics, and evaluation techniques of new and sometimes complicated materials. They reflect this knowledge in standards and specifications, thereby frequently leading industry or commercial production just enough to cause improvement in production facilities and methods which give a profitable quality-assured product that meets not only the DOD specifications, but frequently is an advanced and acceptable item for the commercial consumer.

The Government pay level in recent years is such that agencies such as ours are quite competitive, insofar as salaries are concerned, with non-Government activities. Thus we attract and hold a competent staff in the scientific and technological fields. We choose versatile people and sooner or later this versatility pays off in a shift of emphasis to more needed research.

Facilities

I will not try to list for you the facilities that the Army has for materials research. Perhaps if I name the major segments of the Army Materials Research Agency, you can sense the breadth of facilities devoted to materials research. These are laboratories for:

Materials Research (Basic)
Nuclear Research
Interdisciplinary Research
Applied Mechanics Research
Metals & Ceramics Research
Materials Development
Processing Research
Materials Testing

Each of the above has branches, generally three or four, devoted to specialties. As an example, the Processing Research Laboratory has the branches for:

Shaping Technology
Casting and Cermet Technology
Metals Joining

AMRA currently occupies about 300,000 square feet of laboratory and administration space, and the closing of the production activities of Watertown Arsenal has had one compensating feature. It releases buildings and space for AMRA activities. Thus the growth pattern presents no insurmountable problems insofar as buildings are concerned. Those of you who have been in the Materials Research Laboratory (Dr. Beeuwkes' and Dr. Priest's bailiwick) have seen what can be done at moderate cost by converting a former electroplating shop into very acceptable research laboratories. We expect in time to convert other buildings into suitable research and development facilities.

Equipment

Over the years the staff has anticipated the requirements for equipment reasonably well. As a result of the planning, and very thankful support from the Army echelons to whom we report, we consider that AMRA has at present most of the essential equipment needed to carry out the R&D programs. We are reasonably assured that the current requests for a mass spectrometer, a pulsing device with capability of sensing transient response under high dynamic loads, among other equipment, will be honored to fulfill current needs. Later today my staff will report to you some of the results of their programs on existing equipment and where they believe they must go in the years ahead.

I would like to tell you of one of the newest and major research tools that the Army has. It is officially the "U. S. Army Materials Research Agency Research Reactor". This reactor is a one megawatt, light water moderated and cooled, highly enriched uranium, thermal type that is constantly used by the scientists of the Materials Research Laboratory and the Nuclear Research Laboratory for such projects as:

Effect of Temperature on the Electron Distribution in Metallic Materials

Lattice Dynamics of Explosives

Low Energy Molecular Motion and Lattice Vibrations in Polymers, Hydrocarbons and Organic Compounds

Low Temperature Long Wavelength Nuclear Studies on Sapphires and on Single Crystal Metals

Form Factors in Magnetic Materials by Use of Polarized Neutrons

Study of Short Range Order and Dispersion Relationships of Lattice Vibrations in Alloys

These are the kinds of studies that must be made if we are to know how to improve materials on a truly scientific basis without resorting to extensive experimentation.

In a survey made not too long ago, it was ascertained that materials researchers in universities and industry have noted that the realistic cost of research increases about five percent each year. This factor is actually as high as 10 to 12 percent per year in research laboratories that utilize equipment having very short obsolescence periods. This is a costly business and thankfully we do help one another, mostly under contract, by undertaking programs where competence and expensive equipment is already in existence. We too are taxpayers and I assure you that if we can promptly buy materials research we will do so and not go the other way of procuring equipment and undertaking the job ourselves.

Requirements - Knowledge of What is Needed

Not long ago most Army items were simple and uncomplicated, and there were years of experience behind each item. The accomplishment of improvements in these items by supplying new or improved materials was not too difficult. At AMRA and its predecessor agencies, we weighed the needs of the Army systems and geared our materials research to produce materials that would give increased performance. In this relatively uncomplicated manner we kept pace with the materials needs of the Army.

Our early pioneering effort with the metal titanium, around 1948 when the small quantities available were brittle, has paid off. This is a good example

where the recognition of the potential use of titanium in defense and the sponsoring of research and development thereon resulted in a fully acceptable engineering metal.

Between 1950 and 1955 in our Materials Research Program we learned how to control interstitial elements to eliminate their deleterious effects, to melt in high vacuum and to join in inert gas-shielded atmospheres. Side effects of course have been the use of some of these metallurgical procedures almost in a "metallurgical revolution" to allow marked improvement in other more common and in some of the reactive metals. Consumable electrode vacuum-melted steels now have premium qualities and welded joint efficiencies in many metals are much improved.

These are "payoffs" from the titanium program in which the Army pioneered and had a strong effort. This metal, as you know, is now available in quantity, is used in Army, Air Force and civilian aircraft (the supersonic transport is a fine example), in the chemical processing industry, and elsewhere.

For ballistic protection, i.e., armor, titanium offers some marked advantages; thus application of existing knowledge and of the safe ballistic limits of the newest alloys have shown areas in land and air vehicles where titanium alloys outrank other materials.

Our current programs in beryllium and in uranium have not the extensiveness of the earlier titanium program, yet these metals offer much promise.

Even as late as when the first antimissile-missiles were on the drawing board, we and associated DOD laboratories had anticipated 70% of the materials research needs for such vehicles and had programs underway that would yield materials for those systems and similar prototype items before they were actually needed.

Today we have a vastly greater sophistication in the Army equipment and we can seldom afford trade-offs because the best materials are not available. We must, therefore, have a method that analyzes materials requirements at the concept stage. We think you would like to know more about the system. We have, therefore, placed an item on the agenda that will cover the approach. It represents a new way of life for us for it takes away the very difficult problem of deciding the specific materials on which research is to be accomplished; the method focuses attention on the current real needs. We consider this to be an efficient planning medium and a logical way of establishing a prominent part of what should be accomplished in the Materials Research Program.

Dissemination of Information

Dissemination of information is always a vexing problem. We tackle it in many ways using the following media.

a. Technical and Memorandum Reports, Technical Notes and Monographs which are given as wide circulation as the law allows, always striving to

have as many of the publications unclassified as possible so that they can reach the greatest number of interested readers.

b. Through symposia and conferences. One outstanding annual symposium that we hold was mentioned by Colonel Black. It is the Sagamore Materials Research Conference. The subject is chosen yearly in a field in which we are planning to move more extensively. We know that, by holding a four-day meeting with national and international scientists freely presenting and discussing the field, we acquire a deep insight into the state-of-the-art and the fields for research endeavor for the chosen subject. The information obtained at the Sagamore Conference is frequently a starting point for many of our research programs, and on two of the Conferences the proceedings are available as technical books.

c. The Materials Advisory Group (MAG) and its Technical Working Groups (TWG) are composed of representatives of all of the AMC laboratories that have research underway in a given field. There are nine of these TWG's - one in each category of materials research. In the annual updating of the Five-Year Materials Research Plan, the members discuss in depth the available information on a subject and recommend the course to follow. Additionally, the TWG's hold meetings on specific subjects (castings, corrosion, etc.) to which the hardware people are invited so that they may know of, and will utilize, the newest materials.

d. Attendance at, and presentations to, the national professional societies are recognized as essential, and the holding of office of the working groups or committees of these societies is encouraged.

The dissemination of information, of course, is one of the real reasons you are here today. We hold both formal meetings, as this Advanced Briefing, as well as informal meetings at your laboratories and plants throughout the year. As our Commanding Officer has mentioned, all of these aid in dissemination of scientific and technological information.

Industry's Role in Fulfilling the Army's Requirements

We think that this requirement will be capable of accomplishment mainly by your knowing of our problems. A staff member giving a talk recently to a business group at the Harvard Club of Boston was not surprised, after he had described our Materials Research Program, to hear: "Your market analysis is all done for you--how lucky can you be!" It obviously isn't that simple, but by sharing our planning information for long-range and short-range periods and by keeping on our toes we do have time between concept and first prototype manufacture of a new system, to perform research, test, and evaluate new materials that fit the application.

It is the mission of briefings of this type:

(1) to alert you of the materials requirements of the Army;
(2) to have you learn of our thoughts for research on new and improved materials.

(3) for the Army through AMRA to be receptive to any input made (a) on research that is underway, (b) on research just completed, or (c) on your capabilities to undertake research.

Our budget is not "fully elastic". We stretch it as far as we can. Many times we have great interest in a particular research task but we just are not able to fund it. In these areas patience is a great virtue both on your part and on our part.

I do think you are anxious to hear from those on the scheduled program. May I conclude by thanking you for participating in this briefing.

CHAPTER II

The U. S. Army Combat Development Command (CDC) has the responsibility of advising the Army Materiel Command (AMRA is a part thereof) of the type and kind of warfare envisioned for the future. The manner in which (a) this facet is gradually evolved for future blocks of years and (b) the depth of the planning function to eliminate unneeded effort and allow concentration on required effort were offered by the CDC representative.

FUTURE WARFARE CONCEPTS

Major Albert F. Green
U. S. Army Combat Developments Command
Directorate of Materiel

Gentlemen, it is a pleasure to address you today and to speak to you briefly on the United States Army Combat Developments Command.

The Combat Developments Command was established 20 June 1962 as part of the reorganization in that year of the United States Army. The purpose of establishing the Command was to centralize all functions and activities falling within the Combat Developments spectrum of land warfare.

In the final analysis, the mission of the Combat Developments Command is to keep alive the dynamic of land combat.

In Figure 1, you see the three fundamental elements of land combat: man, his weapons, his mobility means. The proper relationship of these three elements is the dynamic of land combat. Weapons change, the means of mobility change, man himself changes, but the dynamic of combat remains the proper relationship of these three elements.

As the history of warfare shows, fire and movement are the basic elements of the art of warfare, and combat power results from a skillful blending of these elements plus the moral strength of a military force.

The means the Army uses to keep alive the dynamic of land combat and assure the capability of the Army to fulfill its missions unlimited is called Combat Developments. The definition of Combat Developments is:

> *"The Process to increase the COMBAT EFFECTIVENESS of the ARMY in the field as RAPIDLY as possible at REALISTIC COST through the ORDERLY DEVELOPMENT & INTEGRATION into the Army of NEW or IMPROVED DOCTRINE, MATERIEL & ORGANIZATION."*

Note that Combat Developments is a process. It is not a random search for a possible answer to a problem but a series of actions or operations leading to

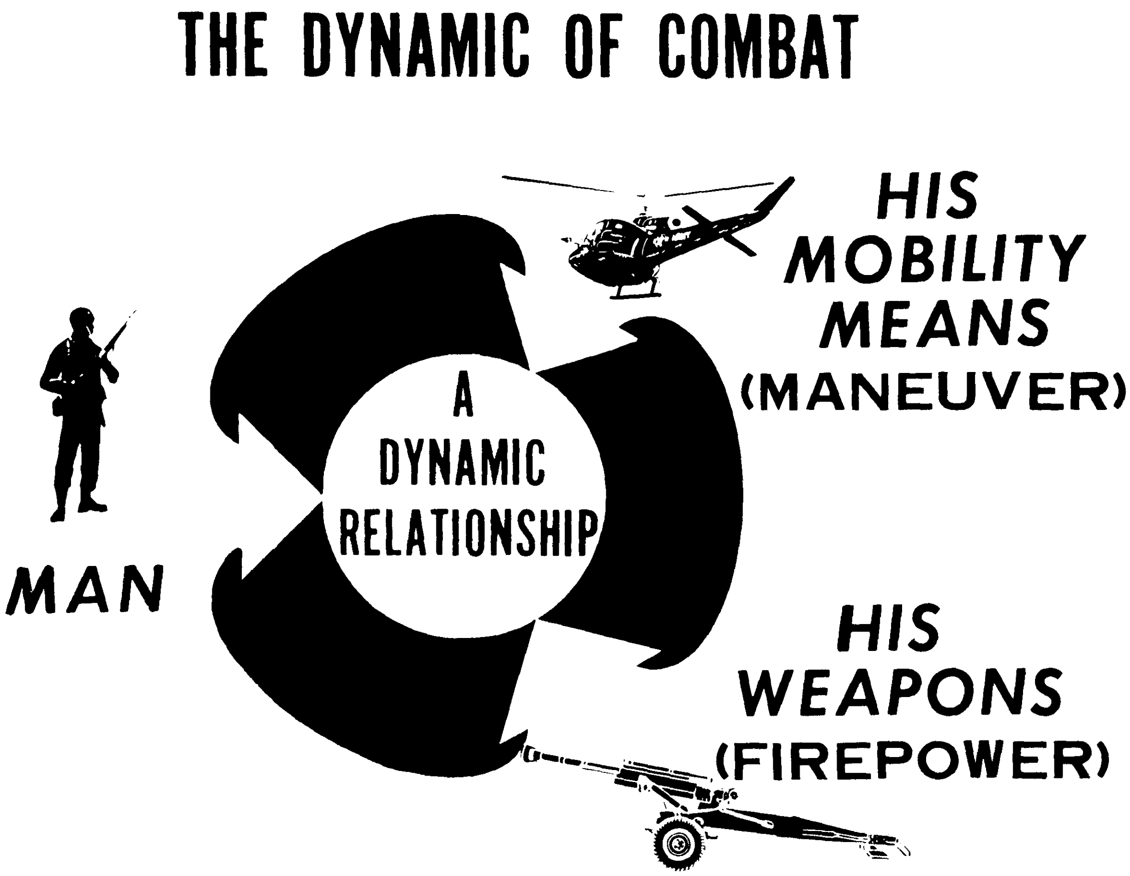


Figure 1.

a well-defined end or purpose. The purpose is to improve the combat effectiveness of the ARMY in the field by which is meant all types of military personnel and units utilized in, or intended for utilization in, a theater of operations.

Realistic costs implies supporting conclusion with cost-effectiveness studies. Experience has shown that there is a dynamic relationship between actual cost in dollars and military effectiveness.

The Army must be ready to perform its mission effectively at all times. The development and integration of new or improved doctrine, materiel, and organization must never cause such a gigantic upheaval in the Army that the troops in the field cannot perform their readiness mission.

During the past year, the Combat Developments Command has subjected its Combat Developments process to a detailed and comprehensive analysis, using the techniques and methods of operations research. This analysis has revealed that every Combat Developments action, whether it concerns doctrine, materiel, or organization is capable of integration and correlation with every other Combat Developments action within its own time period. From this analysis a comprehensive system has been developed for application to the Combat Development process within a stated time frame. This system, designated the Army

Concept Program is:

A program to facilitate integration of new or improved doctrine, materiel, and organizations into the Army in the field during a designated period.

Each Army Concept Program covers a designated five-year implementation period. Current Army Concept Programs are Army 70, Army 75, Army 80, Army 85, and Army 90. The date signifies a five-year period ending in the fiscal year stated. Thus, Army 70 refers to the time period FY 1965 through FY 1970; Army 75 to the time period FY 1970 through FY 1975, and so on. As of 1 July 1970, Army 70 will be dropped since its implementation will have been completed and Army 95 will be added.

The projection of the Army Concept Programs over a 20-year period brings Combat Developments planning into consonance with the period covered by Department of the Army Planning and the Army Family of Plans, which will be discussed later.

Each Army Concept Program includes the concept study, supporting doctrine studies, and all derivative Combat Development actions necessary for timely implementation. The more detailed composition of the Army Concept Programs will be described later. Here it is sufficient to note that each contains the studies, experimentation, and all Combat Developments actions which become the basis for modeling the Army of the future for the particular time period represented by that program.

Put more simply, each Army Concept Program provides for its particular and specific time period the answer to the three basic questions shown:

1. *How should the Army fight?*
2. *How should the Army be equipped?*
3. *How should the Army be organized?*

Notice carefully the sequence: fight, equipped, organized. We do not take the hardware and then figure out what to do with it. We first decide how we want to fight and then ask ourselves, "What do we need to fight with?" and "How can we best organize ourselves to do the fighting?"

Experience has shown that there are five principal factors that affect Combat Developments, as listed below:

1. *Must keep Concepts geared to reality.*
2. *Must keep Doctrine - Materiel in balance.*
3. *Must represent needs of the "User".*
4. *Must reflect--and/or "Push"--the scientific State-of-the-Art.*
5. *Must consider Cost Effectiveness.*

The first is that Concepts must be geared to reality. They must be geared to developing an Army responsive to the threat that actually confronts us or

may confront us, and not to what is in somebody's mind. To keep Concepts geared to reality, they must be in consonance with the Department of the Army Family of Plans. These are the basic Army Strategic Estimate and the Army Strategic Plan, which project strategy and objectives for the Army for the next 20 years - and the Army Force Development Plan which contains guidance for the phasing of new systems into the Army and the programming of new troop units. Information on the probable enemy is derived from every available source of nationally approved intelligence. In addition, contact with the scientific and industrial community is maintained to insure that the Command is kept abreast of technological advance.

Second, doctrine and materiel must be in balance.

In other words, the materiel tail must not wag the doctrinal dog. History clearly teaches the penalty paid if doctrine and technology are not kept in balance.

Third, the needs of the user must be represented. The user here is the Army in the field. We must see to it that the Army in the field gets the doctrine, materiel, and organization that it needs, and conversely that it needs what it gets. There is a fine distinction between these two and one which is somewhat delicate both to determine and to apply.

It is no secret that the military --- with some notable exceptions --- have been conservative in making their selections from the menu of radically new ideas proffered by the scientists and engineers. The reasons are many, and include intersecting economic, institutional, bureaucratic, and doctrinal constraints or checks. Financial considerations and the need to maintain effectively organized and trained military forces call for an appreciable degree of stability. We must not, however, allow ourselves to be smothered with obsolete and truly redundant units, facilities, equipment, supplies, or doctrine, which not only stifle our strength but deny resources which could well be put into military innovations.

What we must do, is to eliminate on the one hand the obsolete from our structure; and on the other hand to encourage both vigorous basic and applied research and their exploitation in those areas where real gains can be envisioned. This is a formidable task --- but it is one we must face squarely if we are to keep pace with the rapidly changing technological and ideological milieu of our times.

Fourth, our requirements must reflect or "push" the State-of-the-Art.

When a requirement is within the State-of-the-Art, we must try to obtain the best possible item currently available. When a requirement is beyond the State-of-the-Art, we must knowingly ask for something not currently available, thus pushing the scientists and industrialists to see if they can produce it. On both counts, we must keep fully informed of the current State-of-the-Art and of scientific and technological as well as industrial advances.

Lastly, we must consider cost effectiveness, which is the dynamic relationship between actual cost in dollars and military effectiveness. The goal of the cost effectiveness concept is the best utilization of total resources. In applying this factor, however, we find the cost element much easier to determine than the element of military effectiveness. The costing of military systems has been developed to a new and higher standard of perfection under the extensive guidance of the Department of Defense. However, before the cost effectiveness ratio can be determined, a number must be placed on the military effectiveness element. Here we run into difficulty, and land warfare has defied quantification so far. Comparative firepower can be quantified; but the basic objective in land warfare is to maneuver men into positions from which they can control key areas and the people therein. How do you quantify maneuver or the other intangibles such as morale, leadership, generalship, training, not to mention deception or surprise which can unbalance.

Within the Combat Developments process itself, five phases have been identified as shown below:

1. *Development of Concepts.*
2. *Development of Operational Doctrine and Organizational Outline.*
3. *Development of Resultant Materiel Requirements.*
4. *Development of Detailed Organizational Structure.*
5. *The Test to Determine the Validity of Other Phases.*

In Phase 1 the broad guidance and general objectives which determine the direction of Combat Developments are developed. The Concept must be sound. It must consider all the functions of land combat, be without gaps, and must be aimed at making the fullest utilization possible of all current and future technological advances. If we believe the principles of war, it must be in accord with the best long-range guidance obtainable about the present and the future threats. Combat Developments Concepts are thus closely related to the Department of the Army's long-range plans, strategic forecasts, and to the missions of the Army as they are projected for stated periods in the future.

Once the Concept has been developed, it must be spelled out in more detail. This is Phase 2 of Combat Developments and is known as the Development of Operational Doctrine. In this phase are developed the Operational Doctrine and Organizational Outline needed to implement the Concept developed under Phase 1.

Phase 3 is the Development of Resultant Materiel Requirements. In determining these, consideration must be given to how the Army should be equipped to carry out and support the Doctrine developed in Phase 2.

This is followed by the Development of Detailed Organizational Structures, Phase 4, which entails putting together people and materiel in the best possible arrangement to get the job done.

Lastly, the validity of the other phases is tested. Actually, test and evaluation are used throughout the Combat Developments process and at each stage of development. By constant evaluation and test, Combat Developments is kept on the right path and each successive phase tested for its validity.

The methodology of the USACDC Program is shown in Figure 2.

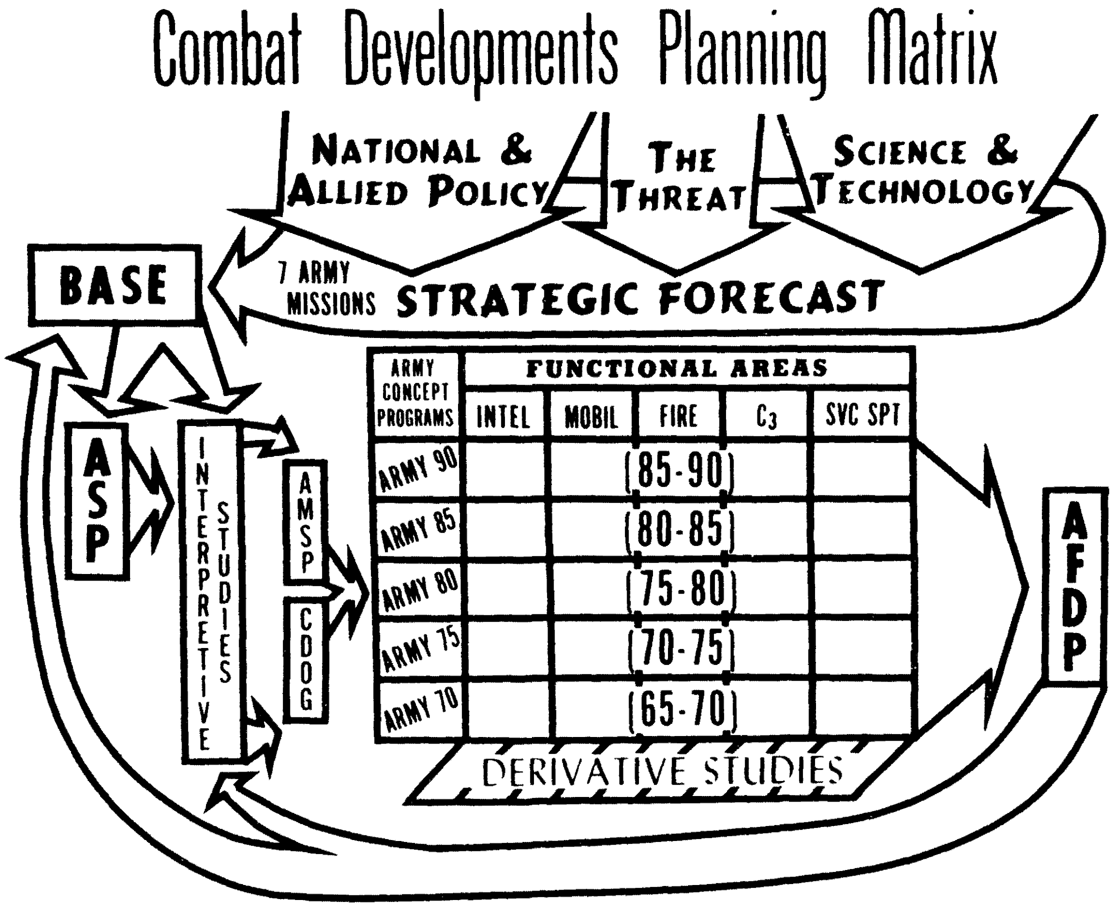


Figure 2.

From such broad Concepts as national and allied policy, the threat, science and technology, and the seven Army missions, the USACDC Institute of Advanced Studies prepares on a biennal basis the very long range strategic forecast. This forecast is used, with other data, by the Deputy Chief of Staff for Military Operations, Department of the Army, as input for the Basic Army Strategic Estimate or BASE. The Deputy Chief of Staff of Military Operations also prepares the Army Strategic Plan or ASP.

From BASE and ASP, by means of interpretative analyses, the Combat Developments Command extracts strategies, objectives, and program guidance and generates the requirements for the Army Master Study Program (AMSP) and the Combat Development Objectives (CDOG). These documents serve as a partial catalog of our objectives and the basis of our study program.

The matrix shown at the center of chart is the heart of the Combat Developments System and represents the USACDC program. Across the top are the five basic functions of Combat: Intelligence; Mobility; Firepower; Command, Control and Communications (shown on the chart as C_3); and Service Support.

The vertical axis depicts the five-year Army Concept Programs, from Army 70 through Army 90, which have also been discussed.

Each Army Concept Program is designed to portray the total picture of the Army in the Field with respect to Combat, Combat Support, and Combat Service Support, as well as can be foreseen, for a particular time period.

When developed, the Army Concept Programs provide input to the Assistant Chief of Staff for Force Development (ACSFOR) for use in preparing the Army Force Development Plan (AFDP). CDC'S input consists of doctrine as incorporated and published in field manuals; materiel requirements in the form of Qualitative Materiel Development Objectives (QMDO's), Qualitative Materiel Requirements (QMR's); and organizations expressed as Tables of Organization and Equipment (TOE) which prescribe, for each type of unit, the authorized combination of personnel and equipment.

The Army Force Development Plan, in its shorter range aspects, results in guidance for the Army Five-Year Force Structure and Financial Program.

As the figure indicates, the process is cyclic. The changes in the AFDP, reflecting new or improved Army capabilities or reductions in capability, affect the strategy and objectives which will appear in the updating of the BASE and ASP. These, if changed, cause additional interpretative analyses and changes to the Army Master Study Program and the Combat Developments Objectives Guide, thus restarting the entire cycle.

To control the thousands of Combat Developments actions which comprise the total effort of the Combat Developments Command, a unified concept of operations was devised and placed in effect 1 July 1965. This Concept is designed to provide unity of Combat Developments effort throughout the Command, to centralize direction but decentralize authority, and to expedite the production of specific Combat Developments action.

The Concept is shown graphically in Figure 3. The program matrix is a cube, 7x5x5. The side with seven blocks represent the seven Army missions; the bottom of the matrix represents the five phases of Combat Developments; the vertical axis represents the five functions of land combat.

This matrix with its 175 positions, is used in defining the Army Concept Program. Each developmental phase covers all the functions; each phase and function can be considered in its relation to the seven Army missions. Since one of these cubes represents one Army Concept Program, the entire USACDC program consists of 5 such interrelated cubes, with each Army Concept Program correlated with the others.

PROGRAM MATRIX
(7X5X5)

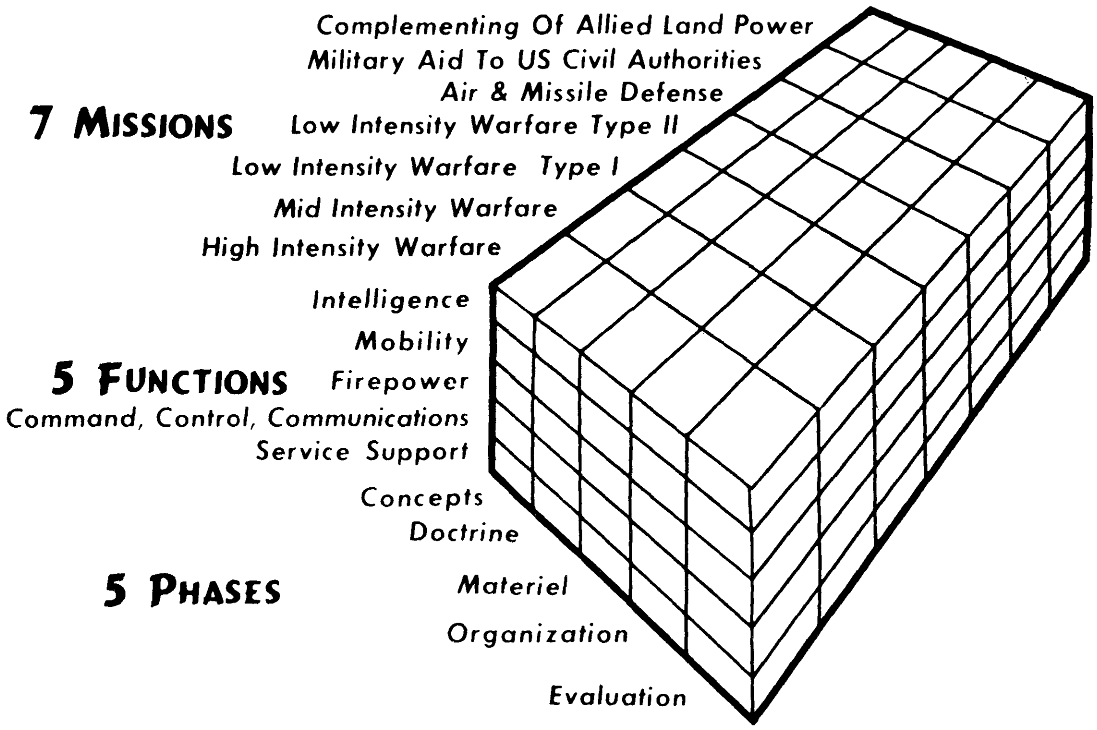


Figure 3.

Figure 4 illustrates one matrix position within an Army Concept Program. The example shown is the Development of Intelligence Doctrine in a mid-intensity warfare environment. The applicable matrix position is the point of Intersection of Doctrine (Phase); Intelligence (Function); and Mid-Intensity Warfare (Mission). By means of this program matrix, any Combat Developments action, be it a Concept study, Derivative Study, Qualitative Materiel Development Objective, Qualitative Materiel Requirements or Reports, can be placed within the total Army Concept Program.

Most important is the use of the matrix as a tool of management to identify gaps or weaknesses in the Program, to show how each action is related to the others, and to assist in identifying the effect each action will have on related programs.

Figure 5 illustrates the development of an Army Concept Program over a period of 25 years. The example selected is Army 90.

The program begins with initiation of the Concept Study which is prepared in the first five-year increment, 1965 to 1970. This study examines each of the five functions of land combat to insure that all elements necessary for operations and ground warfare are carefully considered.

PROGRAM MATRIX
(7X5X5)

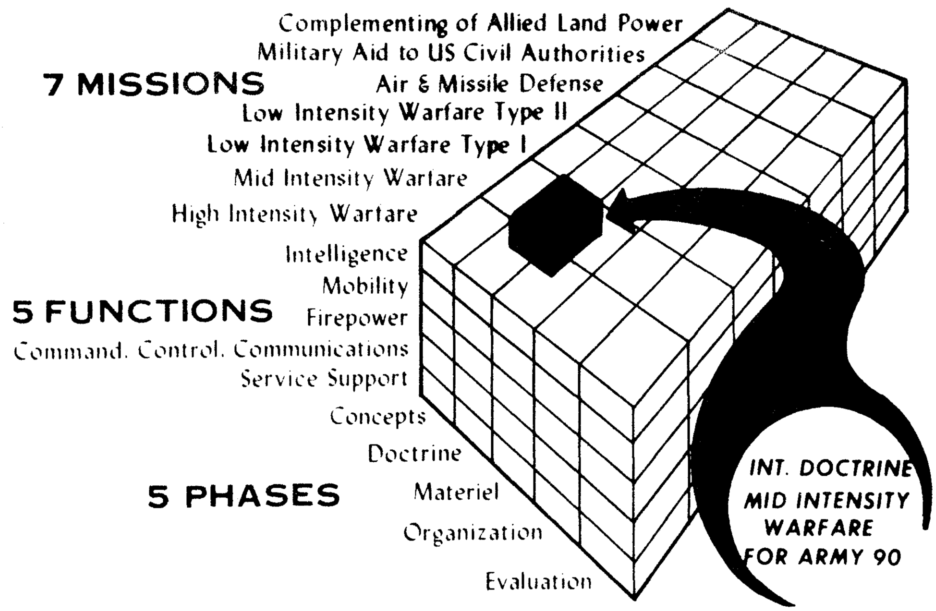
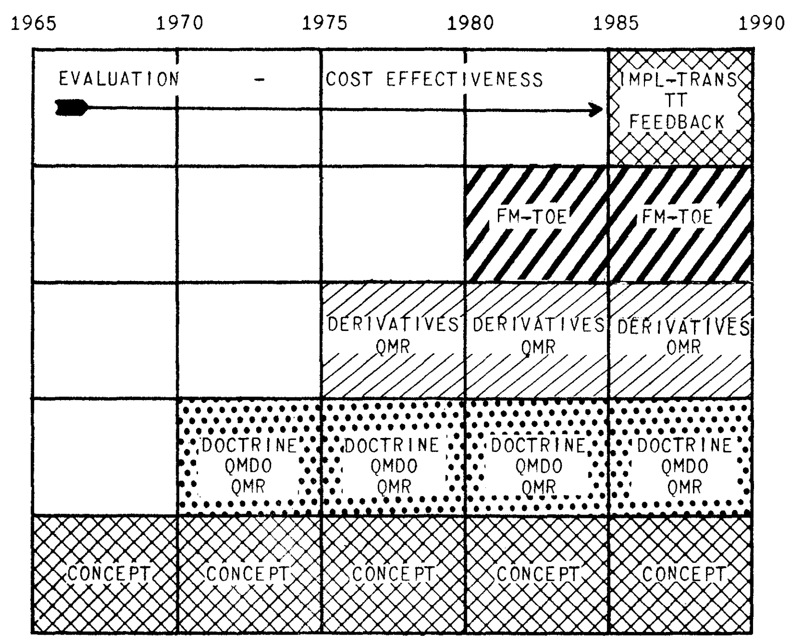


Figure 4.

DEVELOPMENT OF CONCEPT PROGRAM PACKAGE



ARMY 90 (1985-1990)

Figure 5.

During the second five-year increment, 1970 to 1975, the Doctrine Study is prepared. The Doctrine Study is the follow-on to the Concept Study. It examines the functions of land warfare in greater detail and at a level designated the subfunction level.

Take, for example, the function of Mobility. Mobility is divided into three separate aspects: ground, air and water. In developing the Doctrine Study, therefore, the three subfunctions of Mobility are considered: Ground Mobility, Air Mobility, Sea Mobility.

Materiel requirements are also identified and if they are determined to be beyond the current State-of-the-Art, they are developed as Qualitative Materiel Development Objectives (QMDO's).

The Doctrine Study covers the operations of large units -- Division, Corps, Army -- and is the basis for field manuals in the 100-series.

Following completion of the Doctrine Study, derivative studies are undertaken and completed. This state of development takes place in the third five-year increment, 1975 to 1980.

Derivative studies are in greater detail than the Concept and Doctrine studies. They cover the operations of smaller units and are branch oriented -- as, for example, Infantry, Artillery, Ordnance, Transportation, Signal, etc.

During this period the Command also identifies Qualitative Materiel Requirements (QMR's) unique to branch operations and begins to identify Small Development Requirements (SDR's).

In the fourth five-year increment, 1980 to 1985, final actions are completed in terms of end productions, which are Tables of Organization and Equipment (TOE's), and Field Manuals (FM's), either new or revised. The Field Manuals contain certain doctrine which is current for Army 90 and are ready for implementation in 1985.

TOE's and FM's must be considered in most definitive detail in order to avoid gaps and voids in the total Concept of how the Army will fight, how it will be equipped, and how it will be organized within the time period to which the Army Concept Program pertains.

Finally, during the fifth and last five-year increment, 1985 to 1990, the Army Concept Program is implemented and the transition made from Army 85 to Army 90.

During this period the first actual troop tests with units of the active Army are conducted.

Although the troop tests are conducted in the final five-year increment, as shown here, it should be noted that evaluation occurs throughout the 25-year cycle, beginning with evaluation of the draft Concept Study.

In the early phases, the primary means of evaluation are operation research techniques and scientific analysis. During the doctrine period, computerized war gaming can be used as an evaluation technique for Doctrine and Derivative Studies. Field experimentation by the USACDC Experimentation Command must be completed prior to completion of Tables of Organization and Equipment and Field Manuals, if the results are to be fed into the final product.

Throughout the entire cycle, cost effectiveness studies are used to determine the best alternatives from a cost effectiveness viewpoint. All materiel requirements and many TOE actions require cost effectiveness studies.

The entire USACDC Program consists of five Army Concept Programs. The way these programs fit together is shown in Figure 6.

Consider all Army Concept Studies prior to Army 90.

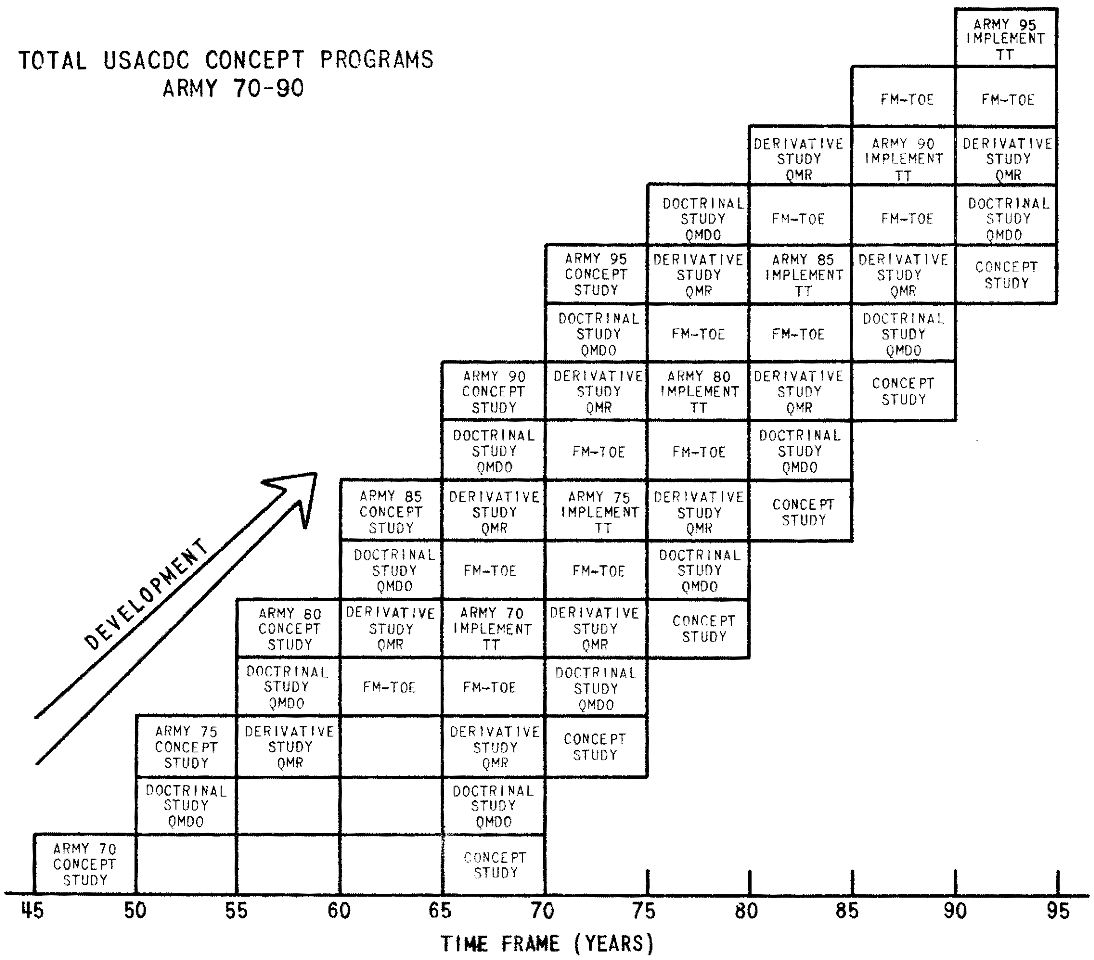


Figure 6.

According to the Concept of Operations, Army 85 should have been initiated in 1960. (It was not, of course; since the Concept was not in existence in 1960. As a matter of fact, neither was the Combat Developments Command). Army 80 should have been begun in 1955; Army 75 in 1950; Army 70 should have been initiated in 1945, at the end of World War II.

Under this Concept of Operations, the USACDC Program maintains an unbroken continuity of its developmental effort. There are no gaps or periods of time when some aspect of the five Army Concept Programs is not being worked on. Moreover, the work on each Army Concept Program is performed logically and in an orderly developmental pattern, culminating in a final Army Concept Program which is a total Concept of the Army for the particular period to which that program belongs.

To illustrate how these five programs fit together during a particular five-year period consider the vertical slice under "Army 90 Concept Study," Figure 7.

In this period, the Concept Study for Army 90 should be completed; the Doctrine Study for Army 85; the Derivative Studies for Army 80; the Field Manuals and TOE's for Army 75; and the Implementation of Army 70.

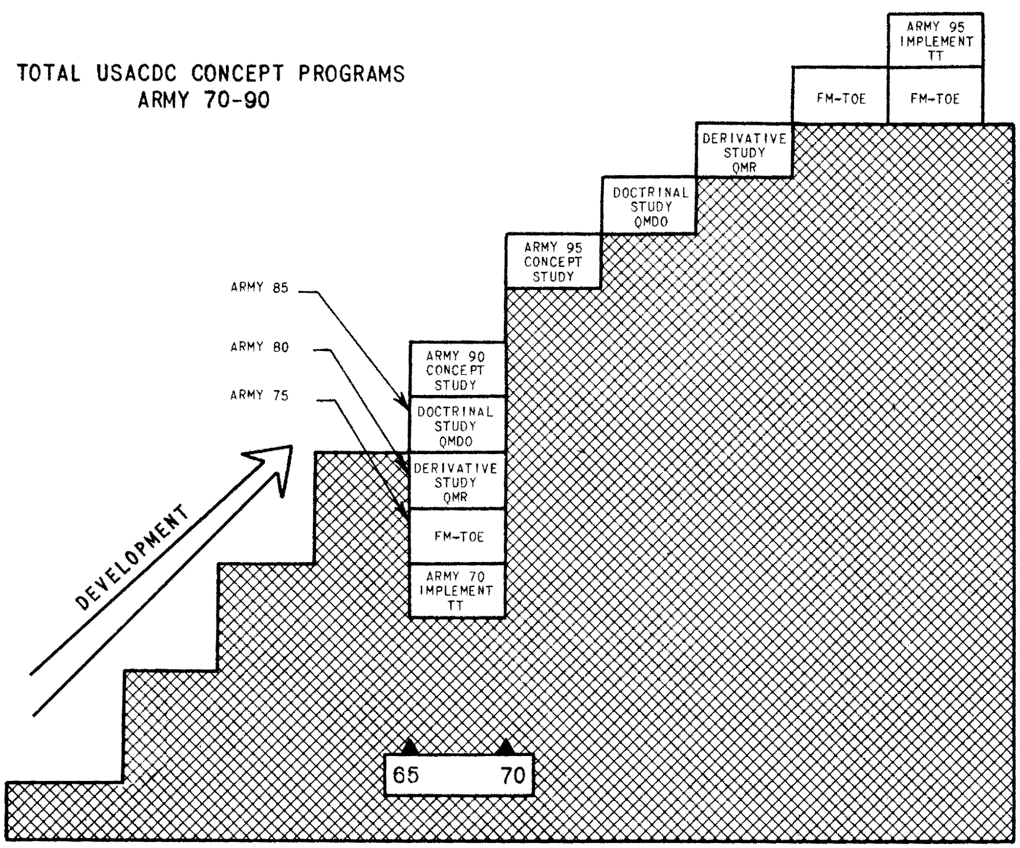


Figure 7.

This vertical slice also illustrates one of the most important aspects of Combat Developments, and that is that there must be no gaps or voids in the Development Cycle. A gap of a number of years in which doctrine is not being developed will mean that in the future years these gaps will appear in materiel, equipment and organization. In short, there is a continuous Developmental Cycle and each Combat Developments action is inextricably dependent upon each preceding or concurrent action. No part of the cycle can be produced suddenly after a void of several years, for voids in one part produce voids in succeeding parts. By carrying on five programs simultaneously but at different levels, the continuity of the Developmental Cycle is maintained.

When one Concept Program has been completed, it is deleted and a new one added. For example, when Army 70 has been completed, it is deleted and Army 95 is added.

Gentlemen, this concludes my presentation. In the past half-hour, I have discussed the role of the Combat Developments Command in today's Army. The Command functions as a catalyst which transforms the needs of the soldier in the field into the appropriate Doctrine, Materiel, and Organizations that the Army requires to carry out its mission, both now and in the foreseeable future.

CHAPTER III

FUTURE ARMY SYSTEMS REQUIRING NEW AND/OR IMPROVED MATERIALS

The Chairman of the briefing noted that the AMRA staff had selected representative inputs from key Army organizations involved in research, development, and planning as typical of the "behind the scenes" activity that is necessary before decision is made on what research will be tackled in order that new or improved performance materials can be available for future weapons or defense systems. It was emphasized that the concepts presented were typical and representative and certainly did not cover all of the Army problems of the future. There was not an opportunity to present any of the systems requirements of the Weapons, Munitions, or Electronic Commands insofar as materials needs were concerned.

Within the Army's responsibility for air vehicles, relatively new families of Vertical and Short Take-Off and Landing, V/STOL, types of equipment and, additionally transport, surveillance, and aerial fire support vehicles are requiring new and improved materials to permit greater efficiencies and performance.

The vehicles used for offensive ground activities, as well as for the movement of men and supplies over a wide variety of terrain and weather conditions, are always in the market for better materials.

New roles assigned to missiles and the need to upgrade performance of existing classes of missiles and rockets create a continuing need for new materials for use therein. The confidential paper on Army Missile Systems is included in Part II of these Proceedings.

ARMY AIR MOBILITY VEHICLES

Donald P. Neverton
U. S. Army Aviation Materiel Laboratories

In order for aircraft designers to obtain maximum aircraft performance, structural materials with the highest possible strength-weight ratios must be supplied. Structural materials must be made available in adequate quantities and at a reasonable cost. The race for low-weight, high-strength structures which has existed in the aircraft industry during the past thirty years is continuing.

Army aircraft are providing a new, efficient, quick striking, warfare capability. The aircraft of the types shown in Figures 1, 2, 3, and 4 which form the modern concept are being utilized increasingly not only as a method of transportation or observation but also as a means of aerial fire support for delivering discrete suppressive fires. The use of such weapon systems in Viet Nam is an example of the support these aircraft afford our ground forces.

The aircraft in Viet Nam are, in general, performing adequately. However, a great deal can be done to improve the aircraft performance and capabilities. Formidable gains through improved materials can be realized.

Several specific areas where further research in materials could afford the most significant contribution will now be discussed.

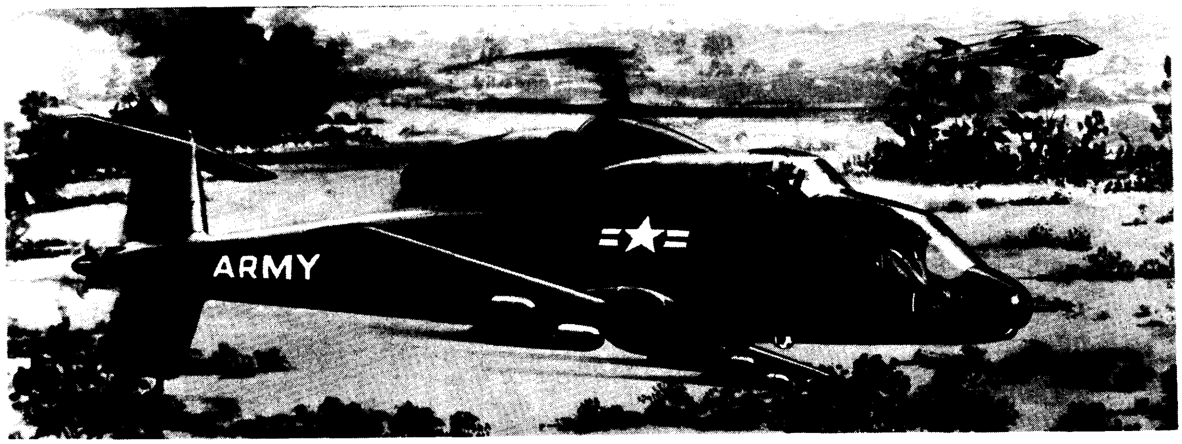


Figure 1.

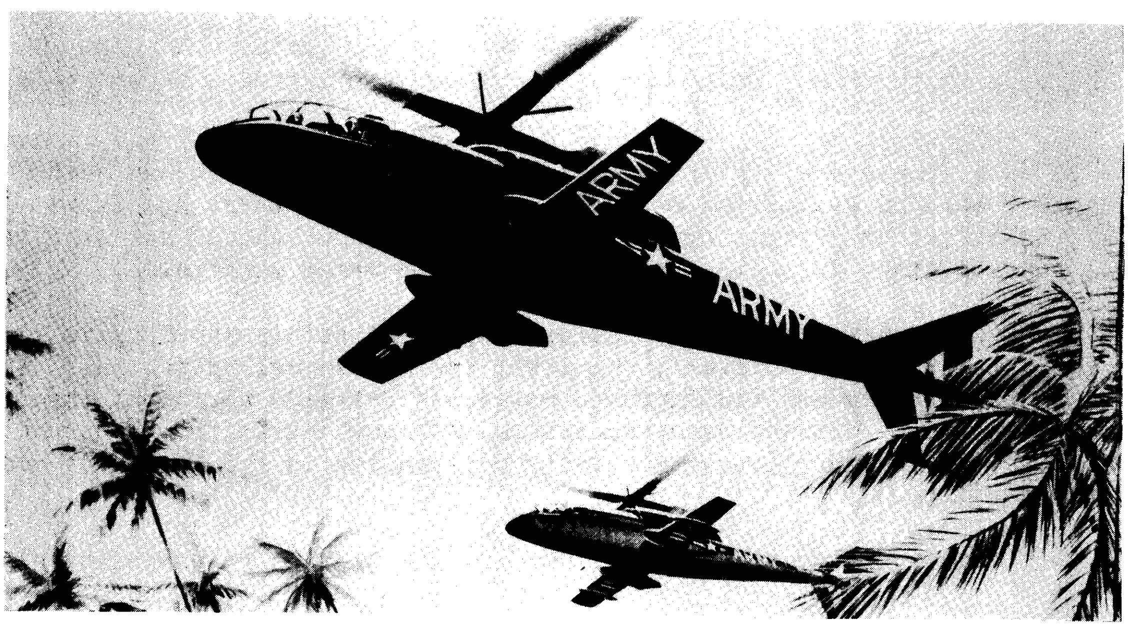


Figure 2.

Figure 3.

Figure 4.

Armor

To date, the overall program of armor materials research has been directed toward an evaluation of the ballistic effectiveness and areal density. Ballistic and weight criteria are important but should not be given total consideration for selection as a candidate armor material.

Research on new and future candidate armor materials should give close consideration to their physical, chemical, and mechanical properties. In order to effectively utilize improved materials detailed technical information is required. Current armor materials, although parasitic in nature, require the following criteria for their utilization in the design of aircraft armor kits.

1. Tensile, compressive, shear bending and bearing stress allowables.

2. Environmental resistance to variable thermal gradients: heat transfer properties: resistance to corrosion, special finish requirements and strain aging data.

3. Flexure fatigue strength.

4. Joining and fastening techniques.

5. Ballistic damage repair techniques.

6. Machinability and workability data.

7. Material availability and projected costs.

The design of armor kits for use in the aircraft has never been optimized because of the rapid evolution of the research programs which have resulted in one material after another coming from the laboratory for use by the designer. In order to marry the optimum qualities of the new materials with the various aircraft configurations it is necessary that a continuous program for improved armor systems be pursued. This program will include crew protection from ballistics and crash and protection of critical components.

Transmission Systems - Use of Dry Lubricants

Adequate lubrication of gears and bearings in VTOL/STOL transmission systems is critical for the proper operation of the aircraft. The occurrence of a lubrication system failure in current turbine powered helicopter transmission systems and drive accessories causes catastrophic failures of gears and bearings within a matter of a very few minutes. In a combat situation, this would result in an immediate abort of the mission with loss of the aircraft and possible loss of personnel. Recently conducted research efforts have shown that solid lubricants have the potential of providing adequate lubrication to both gears and bearings without the necessity of fluid lubricants. Further research in this field is needed. Hopefully, utilization of a dry lubricant as an auxiliary means of lubrication may extend the catastrophic failure time to 30 minutes.

Helicopter Rotor Blade Erosion

The ultimate utilization of the Army helicopter has been seriously hampered because of maintenance problems and short life limits of its various components. During helicopter desert tests, conducted by the Army Aviation Test Board at Fort Rucker, it was found that rotor blade erosion from sand was a chronic problem. In these tests, see Figure 5, the stainless steel leading edge abrasion covering (Arrow 1) was completely worn through (Arrow 2) after as little as 38 hours of operation. The UH-1 helicopter main rotor blades have a service life of 1000 hours. At Fort Benning and Fort Bragg, numerous blades are being retired after 300 hours of operation due to excessive sand erosion damage.

The Army has recently conducted a program to determine the most suitable erosion-resistant material available. The chosen material was to withstand 800 hours in a normal mission profile in desert operations. The material resulting from this investigation was a type of polyurethane. While the polyurethane is a considerable help in the problem, the erosion difficulty

Figure 5.

has not been eliminated. Considerable room for improvement in this particular area presently exists.

Fatigue

The University of Oklahoma recently conducted an engineering survey of aircraft structural failures caused by corrosion, fatigue and abrasion. The prime source of data was the Army failure reports, "Equipment Improvement Recommendation" (EIR). Because of the great number of reports available, a sampling was made consisting of basic airframe failures on four helicopters (UH-1, OH-13, UH-19, CH-34) and two fixed-wing aircraft (U-6, O-1) for the period 1 January 1963 to 31 August 1963.

After screening the repository at the U. S. Army Aviation Materiel Command, some 2,300 reports relevant to structural failures were selected and subsequently reviewed in detail at the University. The review yielded 463 valuable failure reports, all of which were studied and analyzed in detail.

The following results are from an overall point of view and not necessarily from the details of any one aircraft or part.

1. Fatigue failure of fuselage skin (wrinkling) accounted for 7 percent of all failures.

2. Cracks in various metallic components accounted for 47 percent (56 percent of these were in the primary framework, stringer, frame, etc.)

3. Loose rivets accounted for 1 percent.

4. Catastrophic fracture in landing gears accounted for 2 percent.

Fatigue continues to be a major problem in aircraft especially VTOL/STOL concepts. As a further example, let us briefly discuss the XV-9A Hot Cycle Research Aircraft.

The rotor blades of this aircraft are 27 feet in length with a chord of 31.5 inches. The primary structural elements consist of a dual spar configuration. The spars are fabricated of adhesively bonded laminations of AM 355 CRT stainless steel strip with basic static tensile properties of 200,000 psi yielded stress and 220,000 psi ultimate stress.

Initially, this blade was considered to be a 2000-hour flight article. Fatigue tests conducted on root end sections of blades have resulted in a reduction of blade flight time to approximately 65 hours.

Although the mechanisms of fatigue have been investigated by both industry and Government agencies, fatigue continues to be a major source of failure and maintenance problems in VTOL/STOL vehicles. In order to obtain long operational life and reliability in structures, severe weight penalties are frequently incurred. Formidable weight savings and performance gains can be obtained by a reduction of fatigue and fatigue crack propagation problems.

Composite Materials

Composite materials have been firmly substantiated in various applications ranging from rocket motor cases to automotive truck bodies. These lightweight, high-strength, nonmetallic composites offer a virtually unlimited range of properties. The composite structure field is an area which could be exceptionally fruitful for application of future engineering materials.

The Army is constantly striving to obtain stronger, lighter, and less expensive aircraft. Indications are that composites exhibit properties that will enable aircraft manufacturers to produce aircraft with higher strength-weight ratios and lower costs, both initial and maintenance.

Nonmetallic composites offer numerous possible advantages when compared to conventional aircraft structure. To mention a few:

1. Elimination of corrosion.

2. Reduction of fatigue problem.

3. Substantial reduction in numbers of parts.

4. Aerodynamically cleaner design.

Most present day VTOL/STOL vehicles utilize metallic structure in areas of high stress and dynamic loading conditions. Recent improvements in the field of high strength composite structures indicate formidable performance gains for such vehicles through the application of composite structures in areas that previously had been considered for metals alone. The overall potential is significant and further technical effort is necessitated to effect design integrity and reliability for aircraft composite structures.

Helicopter Main Rotor Blades

There has existed a requirement for the development of Army VTOL aircraft main rotor blades which would be both lighter in weight and less expensive to manufacture than current blade concepts.

With the advent of the gas turbine engines and their utilization in VTOL aircraft, available power, which had been the limiting factor in increasing the aircraft's capabilities, is no longer the item retarding aircraft advancement.

For the next stride forward in this field of aircraft, gains must be realized in main rotor technology. The Army is extremely interested in increasing the speed and range of its aircraft. Lighter, aerodynamically advanced rotor systems with higher retirement lives are without question within the capabilities of the materials and fabrication techniques available.

Reduction of Detection of Army Aircraft

In order to lower the detection signature levels of Army aircraft new materials are required. The use of sophisticated weapons systems against Army aircraft dictates that significant measures be taken to lower their detection and acquisition probabilities. The research and development of new aircraft structural and nonstructural materials incorporating passive suppression characteristics is desired.

Infrared Suppression: Lightweight structural materials exhibiting low heat transfer properties, tailored emissivities and low reflectance would be of considerable assistance in the design of infrared suppression devices.

Optical Detection: Transparent materials which offer low reflectance and good optical transmissivity (in the visual wavelength range) would contribute significantly to a reduction in visual signatures. Low reflectance paints, coatings and surface treatments are also desired.

Radar: Aircraft windows and canopies, because they are transparent to electromagnetic radiation are substantial contributors to radar echo returns from the components within the aircraft. The Army is presently striving to obtain the best material or combination of materials that would prevent radar energy from passing through it and degrade or conduct the energy to a minimum or no spectral return and yet retain the maximum optical quality. Research efforts are required in the field of structural materials, coatings or combinations of both which would result in the material acting as a poor reflector of radar energy or as a redirecting aircraft radar reflection.

Materials Requirements in Propulsion Research

Propulsion research is presently concentrated in development of components for an advanced small gas turbine engine (2 to 5 lb/sec airflow) with turbine inlet temperatures averaging approximately 2200 to 2500 F and compressor pressure ratios up to 10:1. The following discussion of material requirements is limited to this particular engine.

Turbine: Although both cooled and uncooled turbine studies are being conducted, only uncooled will be considered here since this concept presents the most stringent materials requirements. Generally, a suitable turbine material must demonstrate excellent strength ductibility and oxidation resistance not only at high temperature but also through the extreme transients expected. First stage stators for example will be subjected to temperatures of up to 3000 F approximately three seconds after light-off. Thermal stresses as high as 125,000 psi are anticipated. Materials must also provide excellent resistance to oxidation and sulfidation (less than 3 mg/cm^2 change desired) as well as withstand erosive effects due to hot gas flow.

The complex combination of thermal and centrifugal loading on the rotating components of an advanced turbine necessitate a lightweight material with high temperature strengths of approximately 60,000 psi. This combination of high temperature strength and low density are of major importance in turbine bucket applications. Good ductibility is required, particularly at the blade-disc attachment. As in the stator, bucket materials will also be exposed to thermal shock, oxidation, sulfidation, and foreign contaminant damage.

Turbine materials requirements are magnified by the small dimensions of the turbine. Stators and blades for this engine are estimated to be approximately 1 inch. In addition, the complex configurations required for optimum aerodynamic efficiency indicate the need for a material exhibiting good machinability.

Compressor: It must be realized that advances in turbine inlet temperature are beneficial only when matched with improved compressor performance. Although the turbine presents the greatest challenge for advanced materials, increased compressor stress levels are inevitable as pressure ratios are increased. The present research compressor requires a yield strength of 75,000 psi at 800 F, a level which is attainable with present day titanium alloys. Further advancements, however, will require use of even lighter, stronger materials.

In a future second generation engine, similar problems of greater magnitude will be encountered as goals are advanced to 3000 F turbine inlet temperatures with compressor pressure ratios up to 16:1. These goals reflect the strong dependence of propulsion advances on materials research and indeed the impossibility of achieving such advances without strong material advances.

ARMY GROUND VEHICLES

John P. Jones
U. S. Army Tank-Automotive Center

The U. S. Army Tank-Automotive Center's mission to provide ground vehicles to support our Army's world-wide operations presents many materials problems that can only be solved by close cooperation with you gentlemen of Industry. We follow your individually generated programs with great interest and work with many of you, either directly or through the Army Materials Research Agency, to meet our specific materials needs. We welcome this opportunity to acquaint you with some of the special materials problems that are generated by our need to operate in extremes of terrain and environment.

We have pieced together a film that shows some examples of the types of terrain and environments (desert, arctic, mud, highway high speed, rough terrain) in which Army vehicles must operate. As you will see, problems are presented that are not normally encountered by civilian vehicles that place special requirements on the materials engineer.

We want fast maneuverable vehicles; thus, we need a high horsepower engine, but big engines are heavy and require a lot of fuel, thus, we decrease range.

We want a powerful gun, but big guns add weight and reduce maneuverability and speed.

We want armor protection, but this adds weight and reduces speed, maneuverability and range.

We want cruising range, but this requires fuel which adds weight - and so, as you can see, our choice is a "trade-off" between these desirable characteristics. We must have technological breakthroughs - particularly in the materials area - in order to make significant gains in overall vehicle performance.

For the purpose of this discussion, I have selected the combat reconnaissance vehicle to demonstrate advances that have been made through the use of new materials and processes. I will use the same vehicle to point out future improvements we hope to make through further materials development. I have selected this vehicle because, in pilot model phase, it represents our closest hardware application of current state-of-the-art in materials.

Before continuing with the new development, I would like to discuss our current combat reconnaissance vehicle, the M41 tank and the M56 self-propelled gun (Figure 1) which is our current airborne assault vehicle. Both of these vehicles will be replaced by the new development. These two current vehicles represent a "trade-off" between firepower, mobility, armor protection, and cruising range within the technology of the 1950's. We feel that these vehicles provide our troops with equipment at least equal to that of any

Figure Ia. GUN, SELF PROPELLED, 90 MM, M56

Figure Ib. TANK, COMBAT, 76MM GUN, M41

current adversary; however they both have serious limitations, particularly in the areas of air mobility and firepower for the M41 and crew protection in the M56.

The next filmstrip shows our latest version of the combat reconnaissance vehicle, the XM551 Sheridan/Shillelagh. This vehicle is presently in the advanced production engineering stages of development and should be in the hands of troops in the near future.

The Sheridan weapon system will introduce into the military inventory, for the first time, a weapon with the dual capability of firing both guided missiles and conventional rounds of ammunition from the same cannon. This system provides the combat troops with a weapon which is a significant improvement over present combat vehicle armament in both lethality and first round hit capability against armored and hard targets, especially at longer ranges. The conventional ammunition, for soft targets and close-in antitank engagements, introduces a completely combustible cartridge case and primer.

The armored reconnaissance/airborne assault vehicle, XM551, is popularly named the General Sheridan. A lightweight, amphibious, air-droppable, armored reconnaissance vehicle, it will also be used as an assault weapon in Phase I airborne operations. The General Sheridan will replace both the M41 light tank and the M56 airborne assault weapon in the Army inventory; however, it possesses far greater firepower, mobility, armor protection, radius of operation and versatility than either of the vehicles it replaces.

Many of the improvements in this vehicle can be attributed directly to the following advances made in the materials field:

a. Much of the increased speed, armor protection and cruising range can be attributed to weight advantages gained by use of new heat-treatable aluminum alloys.

b. The sophisticated firepower system depends heavily on compacted equipment made possible through materials advances in the electronics field.

speed. Polyurethane offers advantages in wear resistance and load carrying ability and is being considered for track application but, here again, cost is a factor.

f. More Extensive Use of Plastics

Fabrication of military automotive components from thermoplastics show promise of simplifying maintenance, reducing vehicle weight, improving fatigue life of springing and shock absorbing devices as well as reducing the need for these devices. Also, sound damping, thermal insulation and the elimination of protective coatings would be added advantages of thermoplastics. Present technology permits the use of plastics in many applications, and current development programs include, more sophisticated use such as filament wound fiberglass torsion bars; however, fabrication techniques, particularly in attachment of plastic components, presents problems.

g. Improved Fuels and Lubricants

In the fuel and lubricant field the ultimate objective is to eliminate the multitude of different weights and grades by the development of one all-weather, all-temperature fluid in each of the areas of fuel, engine oil, gear oil, hydraulic oil, grease, and antifreeze.

h. Improved Protective Coatings

We would like to see the need for protective coatings eliminated by integrating anticorrosion material into the basic material and use painting only for tactical needs; however, we feel that this goal is far in the future. In the interim we seek improvements in the various types of platings and coatings that are necessary to protect equipment in all environments.

Here again, let me emphasize that these eight items do not cover our complete requirements for all types of military automotive equipment - they are merely representative of the type of development programs we need to advance the state-of-the-art in materials for future vehicle needs.

In conclusion I would like to refer to our many evaluations of Russian and Chinese vehicles which have repeatedly shown their design policies of simplicity, lack of sophistication and an emphasis on tactical mass action. As you know, our policy is to provide the best equipment possible and thereby replace human beings on the battlefield with firepower and equipment.

When you consider the vast "hordes" that the Communist world could throw at us in a conventional, nonatomic warfare - fought on their own continent - we cannot consider technological superiority of 2:1, 3:1 or even 4:1 as adequate. We must be vastly superior, therefore, we must have technological "breakthroughs" - not just improvements but "breakthroughs" - that will give us the capability to defeat all potential enemies without paying a heavy toll in American lives.

Some desired future improvements in the reconnaissance vehicle that may be brought about through materials improvements are listed and discussed below.

a. Increased Power

ATAC presently has under development a 1500-horsepower gas turbine engine for tank-automotive use with a maximum volume of 40 cubic feet (maximum dimensions are 28 inches high, 45 inches wide, and 60 inches long). Specific fuel consumption requirements are 0.38 lb/bhp-r at 100 percent power and 0.37 lb/bhp-r at 80 percent power. In order to meet these rigid requirements, designs are expected to have relatively high turbine operating temperatures, for example, 2000 to 2500 F. This temperature and resultant efficiency could be increased even further if materials were available that would withstand these and even higher temperatures. Electrical drives also offer many advantages but are deterred by weight, volume, and cost penalties; and the fuel cell, of course, is considered to be the ultimate power source by many engineers today.

b. Increased Armor Protection

Here we are always looking for improved protection and lower weights. We feel that improvements are possible through new steel and aluminum alloys. Titanium offers immediate improvements; however, technological breakthroughs in the methods of reduction of titanium from ore are required in order to bring the price into a range that will permit its use in automotive application. Also, ceramics, composites, and other exotic materials and combinations offer a wide opportunity to improve protection and reduce weight.

c. Lighter Structural Members

High-strength steels presently offer advantages as structural members such as suspension arms and truck frames; however, difficulties in fabrication and cost deter their use. Also, this is another application where titanium offers immediate improvement but is not generally acceptable because of cost.

d. High Abrasion-Resistant Light Metals

To meet this requirement, consideration has been given to processes that bond steel to aluminum or titanium for components such as track shoes and road wheels. This approach may produce satisfactory results or the answer may be in some hard chemical coating or some other process not yet considered.

e. Improved Rubber Components

Tires, tracks, and mechanical rubber items present special problems in use and in storage. Great strides have been made in rubber development since the start of World War II but shortcomings still exist in the areas of strength, flexibility, wear resistance, heat generation, power absorption, deterioration, availability and cost. Rubber suspension parts are critical since they contribute to shock, vibration damping, and ride control which are necessary for high-speed, cross-country operation; developments in these areas must keep pace with other improvements in order to increase vehicle

In fact, the situation is one where the scientists are still feeling their way, groping in the dark. What has actually taken place is the development of theories of atomic and molecular structure which give a picture to the scientist of what goes on within a particular material at the atomic or molecular levels. This whole pattern may be entirely wrong, but based on the findings obtained by the use of these theoretical considerations, it is possible to predict in many cases what sort of phenomenological characteristics the material will have. Therefore, the fact that these predictions are usually right gives credence to the theory upon which they were based.

I want to make it clear that I am not in any way trying to suggest that a new theory is needed or that the existing theories of the structure of materials are wrong, but merely that they are indeed theories. Nobody has ever seen an atom with electrons orbiting around it in various orbital configurations, nor have they seen molecules in which the atoms are all arranged in regular fashions as they are depicted in molecular configurational diagrams. What we have seen are effects caused by structures and the effects are such that we believe that only the structures described by existing theories could give rise to the phenomena we see.

It is imperative that a considerable amount of increased work in the field of basic research on atomic and molecular structures be carried out because ultimately, it is only from such basic research that the new materials needed to take care of our ever-increasing population, with its ever-increasing material needs can be produced.

Let us examine a few of the cases where basic research in materials has, in fact, proved to give information which has led to a large technological advance. Clearly, the most outstanding current case of this is in the field of solid state electronics. The principle of the transistor is not new nor has it been recently discovered. The principles which give rise to transistor action were known as long ago as 1918. However, it was not possible to realize a useful electronic device based on these principles until a material was developed which had properties such that the theoretical characteristics of such a material could be at least in part realized.

Of course, we all know that the basic research carried out in Bell Laboratories on the properties of germanium is the basis for the tremendous growth of the solid state electronics industry. Had those Bell Laboratories scientists not continued to work without any real knowledge that they were going to achieve a useful goal, but that if they could indeed produce a material whose properties could be controlled to the degree promised by the theory that some sort of an interesting but not necessarily useful device might result, then this industry would never have been born.

As a basic research scientist, I have no idea of the magnitude of the solid state electronics industry today, but it is extremely large and there have been many side benefits which nobody ever dreamed of; such benefits as decreased size, decreased power consumption, tremendously increased reliability. Back when the early digital computers depended upon vacuum tubes and mercury tubes for storage of information, they made a tremendous number of

CHAPTER IV

FUTURE MATERIALS RESEARCH

Approaches (a) to the conduct of effort in the materials sciences and (b) to ascertaining the classes of materials on which the Army should focus its materials research program are described in the two sections of this chapter.

To continue to fill the pipeline of scientific knowledge is a never-ending assignment. In the field of Materials Sciences, AMRA fulfills a segment of the total effort in the portion that has ultimate use as information from which to create materials whose full potential are known, although not yet available, as useful engineering materials.

When Army systems for both defensive and offensive purposes were less sophisticated, it was possible to plan for and execute materials research programs that would satisfy the needs of future generations of weapons. Experience and intuition were necessary and useful factors in determining what should be accomplished, and when materials research programs should be initiated, to assure that needed materials were ready for those who design and engineer major Army weapon, missile and similar systems. Such an approach is no longer adequate; thus, the current method of determining at an early stage the areas on which materials research should be concentrated is described in the section on Design Coupling.

THE NEED FOR BASIC KNOWLEDGE OF ATOMIC AND MOLECULAR STRUCTURE

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Director, Materials Research Laboratory
U. S. Army Materials Research Agency

At the present time we find in the great mass of knowledge accumulated about materials, a very high percentage of phenomenological findings. That is to say, when we carry out certain types of measurements or application of forces to materials, we know how those materials will react under those conditions. It is this type of phenomenological finding which is usually the basis for the use of the materials in the design of some new system. On the other hand, if we try to determine something about the actual structure of materials, that is, the atomic and molecular structure of materials, and the way in which these structural characteristics give rise to the properties we observe, then we find that in reality there is very, very little information available.

There is another aspect to the basic research approach which must not be overlooked and that is, we not only need basic research, we need basic research scientists because the approach of the basic research scientist, if he is a competent man in his field, is one which leads to the maximum degree of creativity.

Thus, a basic research scientist working in the field of materials is not trying to make stronger steel, tarnish-proof silver, or conductive plastics. This list of problems to be attacked is almost endless and is the basis for tremendous expenditures in applied research where the solution of specific problems is undertaken. The basic researcher may solve some of these problems but it will be accidental because he is interested in finding out information about materials. To take the first specific case, that of stronger steel, the basic research man studies how impurities in various concentrations, singly and in combination, interact with the iron matrix and with each other. From a complete understanding of these relationships, it is almost certain that dramatic improvements in steel can be expected, but probably not by the basic research man. His interest is in understanding these fundamental relationships. Once they are understood, the applied researcher and the engineer can make better steel.

The important aspect of the basic scientific approach is that it is without boundaries. The scientist is not trying to make better or stronger steel, but just to find out about steel whether his results lead to better or poorer steel. His interest is in properties; however, they may ultimately be used in actual practice.

I might, therefore, conclude by stating that we need basic research in materials to enable us to understand about atomic configurations, molecular configurations, electronic bonding, cohesive forces, and all the other things which give rise to macro properties so that we can, in fact, modify these fundamental properties which produce the macro characteristics of the material in such a way that we can obtain materials to specifications. The basic research scientist, with his completely free approach to these problems, is the only way that we will make the important breakthrough such as the transistor, the filamentary type materials, and others which are needed. The engineering and applied approach must be carried on simultaneously, the gains there will be slower, they will not be dramatic. Each year steels are a little stronger so that we can use slightly smaller weights of steel to achieve the same results, but it seems clear that the only way that we can achieve steel with 100 times the strength, or even 10 times the strength of existing steels, is by a better understanding of the atomic and molecular forces which give rise to the properties of steel as we now know them. This, of course, applies to all other materials. Until we really understand how the atomic and molecular structure produce the macro properties we see in these materials, we cannot achieve the kind of utilization of the raw materials available to us that we must have to meet the needs of our ever-expanding population.

DESIGN COUPLING - ANALYSIS OF MATERIALS REQUIREMENTS

John J. Burke
U. S. Army Materials Research Agency

The Army has long been aware of the problem of providing "on the shelf" the proper material to meet design requirements of military systems. However, we are all fully aware of the complexity of today's equipment and, likewise, of the stringent requirements of tomorrow. Therefore it becomes imperative that the U. S. Army have an effective system whereby the requirements of the designer be known by those engaged in materials research and development. In addition, the procedure must provide for the transmission of information on the proper selection of a material to the designer. At first glance it appears that such an undertaking is not a difficult task when in substance it is indeed formidable.

I am reminded of the old saw that appeared as a maxim, prefixed to Poor Richard's Almanac in 1757, that highlighted the importance of having the proper materials available when engaged in a war.

"A little neglect may breed mischief,
For want of a nail a shoe was lost,
For want of a shoe a horse was lost,
For want of a horse a rider was lost,
For want of a rider the battle was lost,
All for the want of a nail."

The Army wants to make quite sure that the nail, whether it be a high-strength titanium alloy, a high-temperature oxidation-resistant super alloy, armor for our future combat mobility devices, or components for missiles and aircraft, be not wanting.

There is a limit to the amounts of money that can be allocated for materials research. Therefore, our programs must be responsive to the customer's needs, the customer being the designer and builder of Army weapon systems. In order to discharge our responsibility to our customers we must first be aware of their problems in materials, present and future. The method employed is called "Procedure For Analysis of Systems Materials Requirements" as outlined in the publication of the Design Coupling Group of the Army Materiel Command's Materials Advisory Group. I shall discuss the pertinent features of this document a little later. Before I do this I would like to make a few general observations concerning the proper utilization of materials.

We have available today an excellent supply of materials possessing a broad spectrum of properties. However, a careful analysis will show that only a small percentage are being used to the maximum efficiency. This is more than just a problem of educating the designer as to the properties of materials. The designer may be fully aware of new attractive materials but hesitates to incorporate them into his design because he knows that a time-tested material, perhaps not as efficient, will work. It would be appropriate to designate a

limited number of production items to be built with new materials and then test them and compare their performances with items made from conventional materials. This would allow us to phase in more quickly new materials into our production cycles.

The next problem that one encounters is the proper use of existing materials that must be modified so as to perform in a satisfactory manner. This covers the coating of metals, taking advantage of composite materials, texturing in certain sheet material, or directional solidification in casting and the like.

Assuming that the proper selection of a material has been made and that the proper treatments have been carried out, then comes compatibility with the rest of the system. I can recall instances where a component was designed from materials that appeared to meet all the necessary requirements but later failed when incorporated into the system. A missile systems hydraulic accumulator was made of high strength steel since this allowed a reduction in weight. However, due to the internal pressure and a somewhat corrosive medium, all the necessary conditions for stress-corrosion were present in the pressure bottle. In addition the material had a transition temperature quite close to room temperature. When subjected to storage conditions where rather low temperatures were encountered, the accumulators failed. This condition was rectified by substituting another material more suited for the application.

The point I am making is that many of today's problems could be solved if the materials people would communicate with the designer and vice versa.

What about materials that have yet to be developed? The Army employs two approaches to determine what materials will be needed in the future.

One, we can assume, is that in the metallic area the main structural metals needed in five years will be steel, titanium, aluminum, and magnesium. We can then make a judgment as to the properties needed and we can direct our research efforts to meet our stated goals. The "Long Range Technical Forecast" covers the materials and the range of properties one can reasonably expect to be in existence over the next twenty years. In addition the "Long Range Technical Plan" covers design requirements over a similar period of time. Other documents such as "Objectives for Technology" are available to provide guidance.

The other approach is to go to the designer and future weapons planner and determine what he feels will be needed in the way of materials in the future. A team of material experts, called the "Field Analysis Team," visit the various commodity commands to determine first hand the future requirements of the Army. In addition, this team can provide guidance on the use and availability of existing materials.

It is hoped that these approaches will provide the nail.

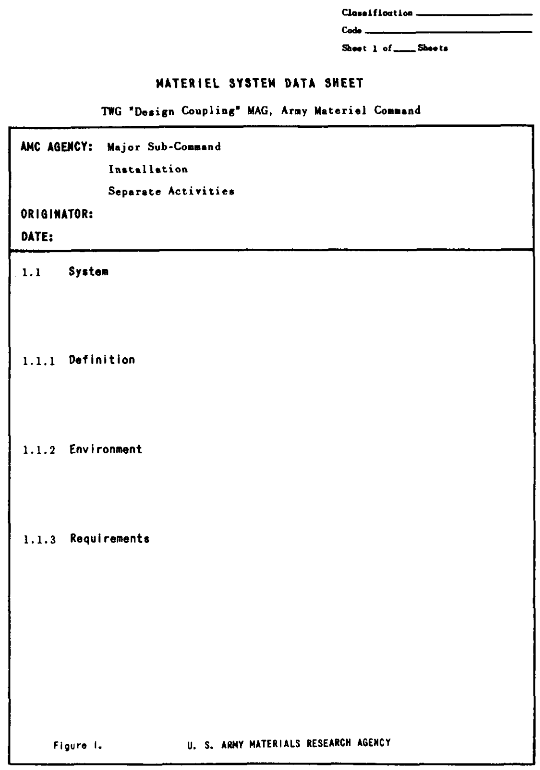
I shall now outline in a brief manner the procedure established for periodic analysis by the Field Analysis Team of the materials requirements of

future Army Systems. The purpose of the procedure is to determine from current and future materiel requirements those materials necessary to provide maximum system effectiveness. All efforts were made to minimize the work of generating, collecting, and analyzing the information.

The procedure is broken down into three phases:

System Identification
Component Identification
Material Identification

Figure 1 illustrates the type of information required on the system. Four categories are listed - the system, definition, environment and requirements.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Sheet 1 of ___ Sheets

MATERIEL SYSTEM DATA SHEET

TWG "Design Coupling" MAG, Army Materiel Command

AMC AGENCY: Major Sub-Command
Installation
Separate Activities

ORIGINATOR:

DATE:

1.1 System

1.1.1 Definition

1.1.2 Environment

1.1.3 Requirements

Figure 1. U. S. ARMY MATERIALS RESEARCH AGENCY

System: The system is identified by taking the proper category from the instruction booklet. For example, under Mobility Device, Surface, there are five possible selections:

Combat Assault
Combat Reconnaissance
Logistic Combat
Logistic Support
Logistic Special

This then defines the mobility devices tactical distribution as previously mentioned by the speaker from the Mobility Command.

Under "Weapons" one has eight categories: Artillery (including Tube and Rocket); Infantry; Airborne Arms; Mortars; Small Arms; Recoilless Weapons; Special Weapons; Fire Control.

Definition: One next defines what the system is: Under "Weapons - Infantry" one would find the following: "Lightweight; man-transportable weapon; rocket motor with armor-piercing warhead; expendable tube launcher."

Environment: The environments to which the system might be subjected would read: "Used under world-wide conditions and a temperature range of -25 F to 140 F. For infantry use, handling subject to dropping, rain, mud, and general field conditions."

Requirements: To defeat light armor and tanks.

Figure 2 indicates the pertinent information necessary to define the component. Due to the limitation on time today, I shall spend only a few minutes on this and the next figure.

Component: One identifies the component using the component or subcomponent list provided in the document "Procedure For Analysis of Systems Materials Requirements." Since the components listed usually refer to assemblies, they must be broken into smaller items until a specific material requirement can be identified with a particular item.

Definition: Under component definition one finds a brief description of the component and the role it must play in the system.

Environment and Design Requirements: Under environment and design requirements are listed quantitative statements of the environments the component will experience during its life cycle.

Classification __________
Code __________
Sheet 1 of ____ Sheets

MATERIEL COMPONENT DATA SHEET

TWG "Design Coupling" MAG, Army Materiel Command

AMC AGENCY: Major Sub-Command
Installation
Separate Activities
ORIGINATOR:
DATE:

SYSTEM:

1.2 Component

1.2.1 Definition

1.2.2 Environment and Design Requirements

1.2.3 Component Design

1.2.3.1 Design Concept - 1
1.2.3.1.1 Assessment

1.2.3.2 Design Concept - 2
1.2.3.2.1 Assessment

1.2.3.3 Design Concept - 3
1.2.3.3.1 Assessment

Figure 2. U. S. ARMY MATERIALS RESEARCH AGENCY

Component Design: This section contains the component design for the major component or subassemblies as listed in the component appendixes. More than one design concept is usually considered. The specific item for which a material requirement is to be determined is identified.

Component performance of the design must be assessed with respect to the environment in order to determine the type and degree of missing capabilities related to material limitations. The assessment also includes: a. Component Performance; b. Relative Costs of the Design Concept; c. Weight and Size.

Figure 3 illustrates the type of data considered important in defining the material properties of concern to the designer.

Material Properties: The analysis of the Design Concepts allows those material properties to be delineated which will fulfill the established component design requirements.

Size: The quantity, size or dimensions of the material and, in addition, applicable tolerances shall be based on the as-order or as-received size. This information allows an assessment to be made of availability of material due to manufacturing capability.

Configuration: The final configuration or geometry necessary to meet the design requirement is stated.

Technology: The various material processing procedures as for instance, forging, bending, welding, drawing, etc., are listed. Any special requirements like surface conditions, etc., which are not standard are noted.

Suggested Material: This is the designers concept of the materials for the intended application based on his knowledge of the state-of-the-art.

Improvement Potentialities: The result of the Analysis is recorded on the Data Sheets. These are used as a guide and justification for certain materials research programs. It is, therefore, necessary to provide data to substantiate the need for the desired material and its properties. This section specifies insofar as possible how the desired material is superior to other existing materials. This should consist of data showing improved component performance, relative costs, differences in weight and size, and estimated quantities of the material or numbers of components to be produced utilizing this desired material.

We have attempted, today, to give you a thumb-nail sketch of one type of approach used by the Army to determine future material requirements of military systems. Other methods are also employed; however, the purpose is the same, that when "tomorrow is today" an adequate supply of advanced materials be available to the military.

Classification ____________
Code ____________
Sheet 1 of ___ Sheets

MATERIAL DATA SHEET

TWG "Design Coupling" MAG, Army Materiel Command

AMC AGENCY: Major Sub-Command
Installation
Separate Activities

ORIGINATOR:

DATE:

SYSTEM:

COMPONENT:

DESIGN CONCEPT:

2.1 Material Properties

2.2 Size

2.3 Configuration

2.4 Technology

2.5 Suggested Material

2.6 Improvement Potentialities

Figure 3.

U. S. ARMY MATERIALS RESEARCH AGENCY

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CHAPTER V

FUTURE MATERIALS DEVELOPMENT AIMS

In each of the sessions of the briefing, a portion was devoted to the existing knowledge pertaining to the specific engineering materials or test under discussion, including the latest information gained by researchers at AMRA and/or throughout the materials community. Each session likewise reached into the requirements envisioned for the material in the future years. It is this later portion that is of greatest interest to the Army and to the materials research community. However, in the case of materials and the continually unsatisfied demands for them, the precise limits or characteristics of materials of the future are usually not definable in as precise limits as one would desire. Coverage of aims, and not goals, for materials for use in future years was presented.

Mr. E. N. Hegge, Chief of the Materials Engineering Division of AMRA, chaired the session on materials development aims, introducing in turn members of the AMRA staff engaged in the individual field. The classified paper on Armor Materials is included in Part II of these Proceedings.

SPECIAL ALLOY DEVELOPMENTS

F. J. Rizzitano
Chief, Exploratory Development Branch
Materials Engineering Division, AMRA

One of the principal aims of "Special Alloy Development" is to explore selected techniques by which improvements may take place in the properties of particular metal or ceramic alloys. Of main concern is the development of structural properties, which involves factors such as strength, ductility, impact resistance, strength to density ratio. Some materials considered in this regard are shown in Figure 1, and indicate the course of development from the year 1950 to where it is likely to be in 1970. The present discussion covers briefly the following materials, titanium, beryllium, uranium, maraging steel, and beryllium oxide.

a. Titanium

In 1950 the tensile strength of existing titanium alloys was of the order of 80,000 to 90,000 psi and by 1964 had been developed to the 180,000 psi level. Much of the pioneering work, including the latter development was

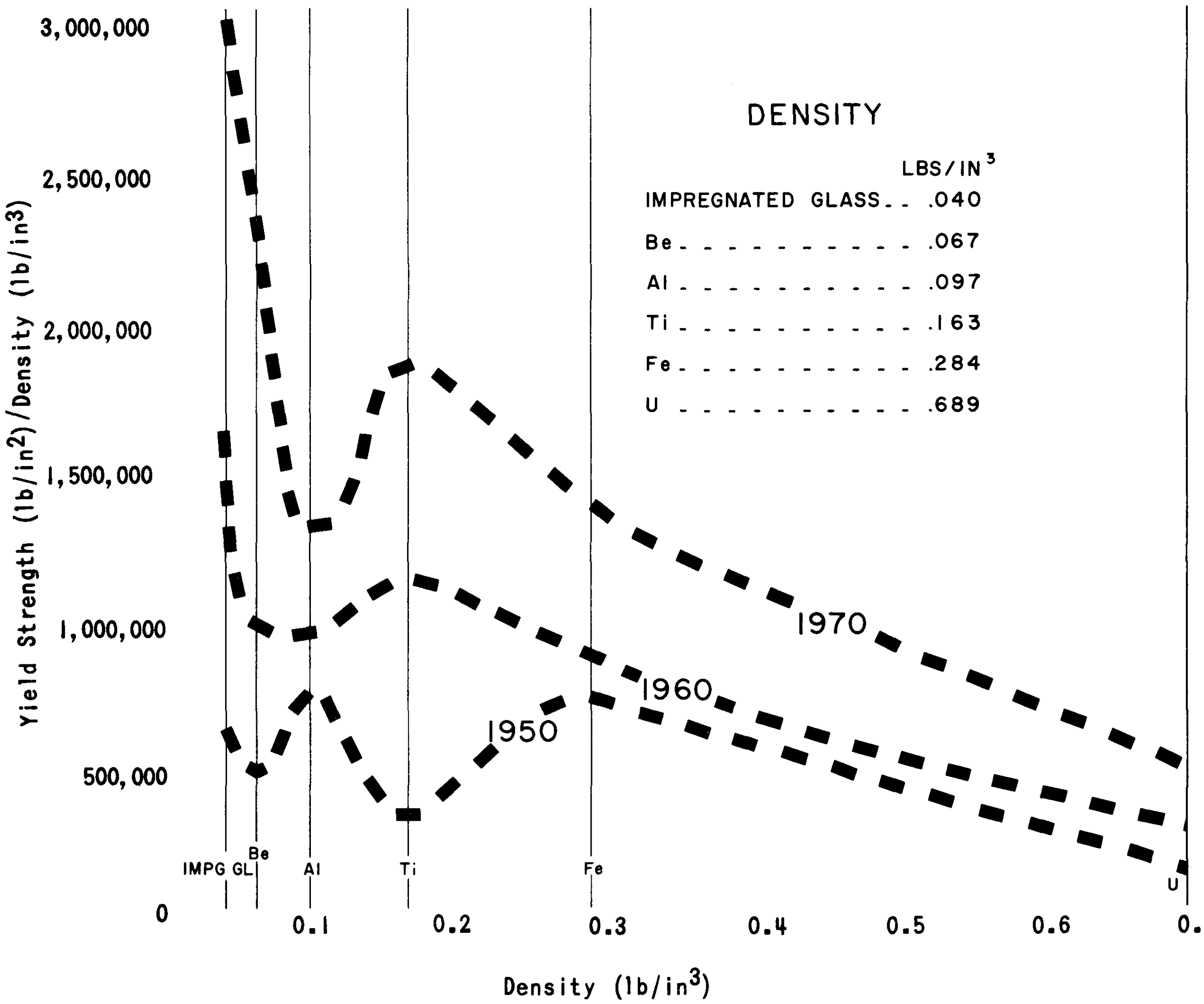

Figure 1. PROSPECTS FOR STRUCTURAL MATERIALS

19-066-1163/AMC-65 Yield Strength/Density versus Density

accomplished by or in coordination with U. S. Army Materials Research Agency. The related strength/density increase was from 500,000 to 1,200,000 inches. Since 1964 further new alloys exhibiting strength approaching 250,000 psi, shown in Table I, have been under development on laboratory scale. These alloys also show considerable ductility and impact resistance. Present and future efforts involve scale-up to 1200-pound ingot size, and evaluation of properties.

High strength/density materials such as these titanium alloys are of significance to advanced weapon or missile systems where weight savings are critical.

b. Uranium

Uranium is a high density material, and its application for structural purposes utilizes only depleted material. This material has special

Table I. SELECTED ENGINEERING PROPERTIES OF TITANIUM ALLOYS

Laboratory Size Ingots - Date first evaluated 1963

Alloy Type	Yield Strength (0.1%) Minimum Requirement (ksi)	Yield Strength (0.1%) (ksi)	Tensile Strength (ksi)	Elongation (%)	R.A. (%)	Charpy V-Notch Impact Energy (ft-lb)(-40 F)
Ti-6Al-5V-2Sn-1Cu-1Fe-3Zr-1Cr-1Mo[a]	200	204	217	9.0	20.0	8.1
Ti-6Al-6V-2Sn-1Cu-1Fe-3Zr[b]	220	222	239	7.3	16.7	6.2
Ti-6Al-6V-2Sn-1Cu-1Fe-6Zr-1Cr-1Mo[c]	240	243	249	5.0	10.9	3.7

a Interstitial Composition (PPM) C- 300; O_2- 900; N_2-230; H_2-20.0

b Interstitial Composition (PPM) C-1100; O_2- 360; N_2-160; H_2-21.9

c Interstitial Composition (PPM) C- 300; O_2-1000; N_2-200; H_2-20.0

19-066-1165/AMC-65

application in several weapon systems where structural properties are important. Development of high strength uranium alloys was initiated at AMRA in 1958, at which time strength of existing alloys was of the order of 110,000 to 130,000 psi. By 1963 development of strength had progressed to the 300,000 psi level as shown in Figure 2. Further metallurgical development has indicated how variations in alloy content and thermal treatment can control hardness, strength, and impact resistance. Developments for the future aim toward improved combinations of strength, ductility, and impact resistance, which appears to be possible by adjustment of composition and thermal treatment.

c. Beryllium

Beryllium, because of its low density and high elastic modulus, is of great interest as a lightweight structural material. Strength/weight ratio as high as 1,800,000 inches has been exhibited by some forgings, and up to 3,000,000 inches by fine wire. The principal problems consist of brittleness and high cost. Development has not yet indicated a real solution to the brittleness problem, but a partial solution may be possible by grain refinement.

Present and future research at AMRA consists of fundamental studies of recrystallization, grain nucleation, and grain growth which can lead to new methods of grain refinement in beryllium.

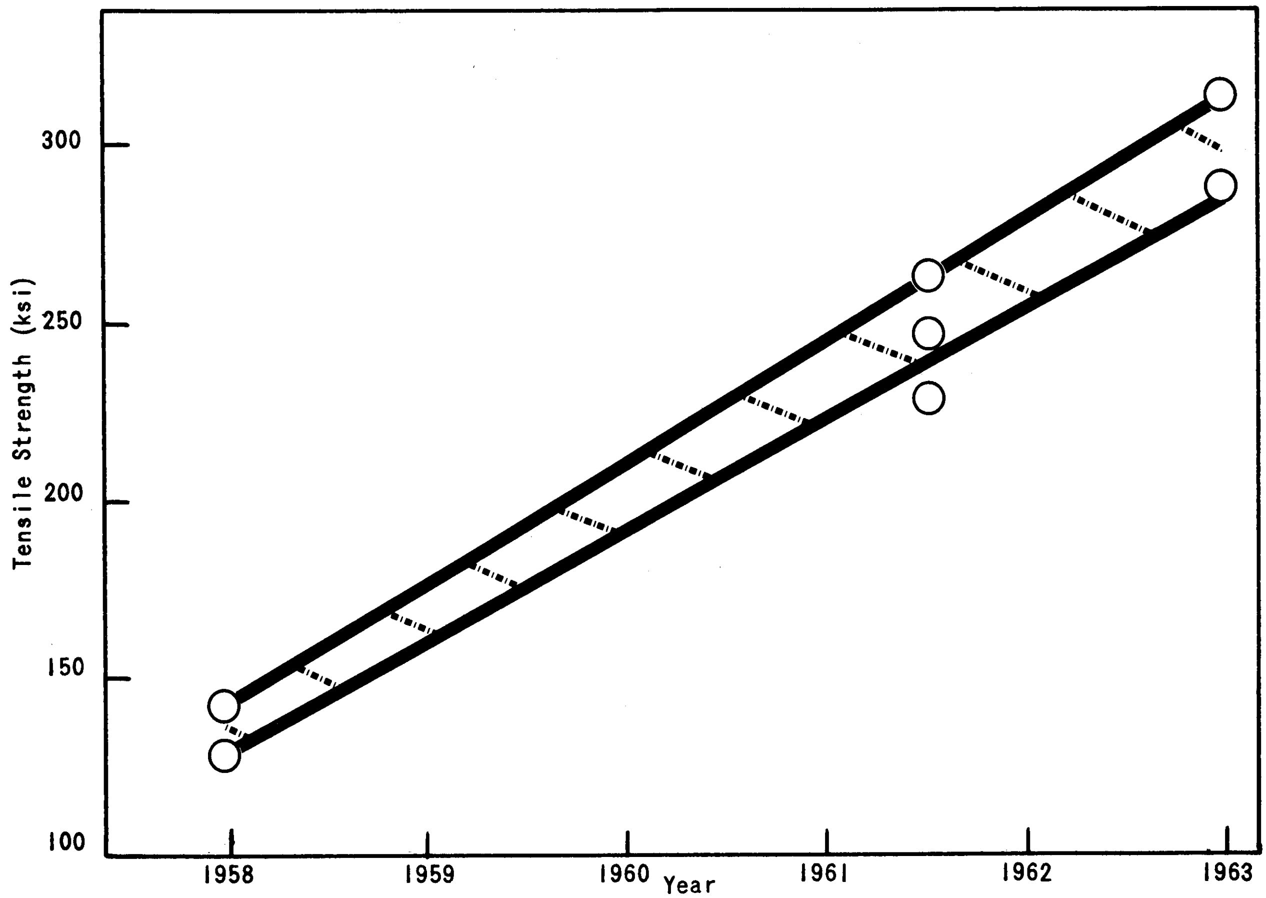

Figure 2. HISTORICAL DEVELOPMENT OF ULTIMATE TENSILE STRENGTH IN URANIUM ALLOYS
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d. Beryllium Oxide

Beryllium oxide exhibits physical properties of interest in areas of electronics, thermal conduction, and neutron reflection. It is a brittle ceramic material of low tensile (10,000 psi) strength and high compressive strength (200,000 psi). There is a current requirement for structural properties in beryllium oxide components such as that shown in Figure 3, for which strength and homogeneity must be improved. To this end, present and future studies involve investigation of new techniques for powder consolidation. Among these are vacuum hot pressing, explosive compacting, high pressure isostatic pressing and hot isostatic pressing. The aim is to eliminate all porosity and retain fine grain size. Additional studies involve the effects of selected "alloy" additions, and development of multiphase systems.

e. Maraging Steels

One of the more recent developments in the steel industry is that of the maraging steels, exhibiting yield strengths in the order of 250,000 psi to 300,000 psi, combined good ductility, and impact resistance. Strength/weight ratio approaching 1,000,000 inches can be obtained. Maraging steels are a product primarily of industrial development. Evaluation program at AMRA has

confirmed these excellent properties. Present and future studies at AMRA probe the possibility of further strength increase by means of small selected alloy additions to the 18 percent nickel maraging steels, together with heat treatment studies.

f. Microcomposites

"Microcomposites" in this instance refers to those materials comprised either of prealloyed powders, or mixtures of powders of different materials. An outstanding development has occurred recently whereby the titanium-6Al-4V alloy, when converted to "microquenched" powder and reconsolidated by extrusion, displayed mechanical properties greatly superior to the starting material. These properties are shown in Table II. Also very significant are the properties of the microquenched composite material containing 10 percent beryllium since it exhibits good ductility and toughness at strength to density ratios exceeding 1.2 million inches. Present and future studies include higher strength titanium alloys which may lead to still higher strength to density ratio composites. Also determination of optimum beryllium content in the titanium-beryllium microcomposites system may lead to lower density and higher elastic modulus.

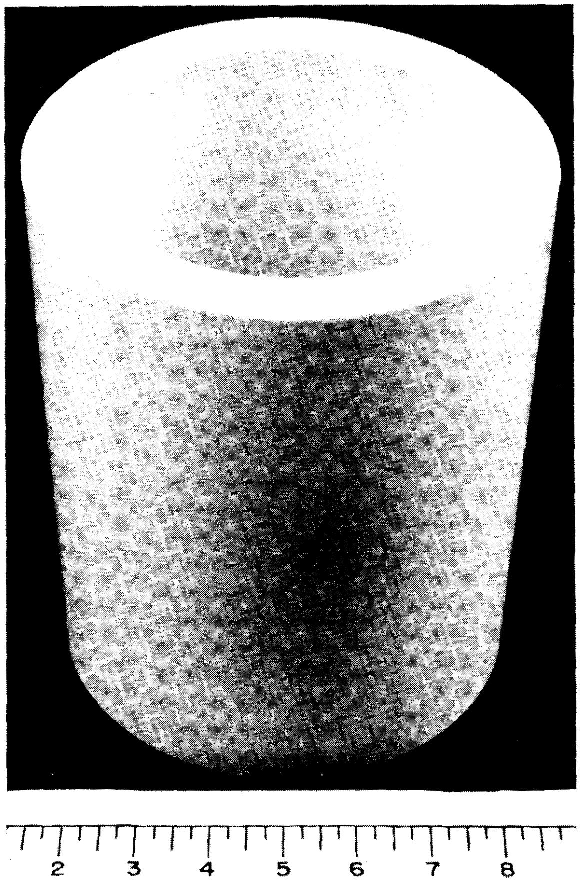

Figure 3. BERYLLIUM OXIDE CYLINDER

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Table II. MECHANICAL PROPERTIES OF SOME TITANIUM MICROCOMPOSITE MATERIALS

	Yield Strength (0.2%) (psi)	Tensile Strength (psi)	Elongation (%)	Elastic Modulus	Charpy V-Notch Impact Energy (ft-lb)
Commercial Alloy 6Al-4V (heat treated)	142,750 143,500	153,750 154,000	12.9 13.6	16.5 16.5	14.0 16.0
Microquenched Alloy Composite (1100 F-Ext) (1050 F-Age)	181,000 202,000 201,000	202,000 203,000 203,000	14.3 3.3 4.0	16.5 16.5 16.5	6.4 6.0 -
Microquenched 6Al-4V Titanium Alloy with 10 V/o Be	188,500 186,500	188,500 186,500	7.5 6.5	16.3 21.0	25.0 27.5
Microquenched 6Al-4V Titanium Alloy with 75 V/o Be	48,100 54,700	48,000 54,700	0 0	- 42.9	0.75 1.00

HIGH STRENGTH STEELS

Eric B. Kula
Chief, Metallurgy Research Branch
Materials Engineering Division, AMRA

From what has been said in previous discussions, it is quite apparent that the Army has a great need for structural materials to be used in lightweight components that must be airlifted. Beyond this, reduced weight is desired in ground equipment, from heavy tanks through soldier-carried weapons in order to make such equipment more mobile and hence more effective. Accordingly, the Army can be expected to have a continuing interest in the use of higher and higher strength level steels.

Currently, most high strength steels used by the Army are quenched and tempered, low-alloy carbon steels. Maximum yield strength levels in use today range from 200,000 to 250,000 psi. In the last few years the maraging steels have appeared. These are carbon-free, iron-18 percent nickel alloys containing cobalt, molybdenum and titanium. These steels are in use at strength levels of 250,000 psi and in some cases 300,000 psi.

There are several areas where it is hoped that improvements could be obtained in the next few years. The first of these is of course the development of still higher strength level steels. The second is the improvement of other properties in high strength steels, such as toughness, weldability, etc., which currently restrict the use of these steels. Finally, it is hoped that there will be a greater appreciation of how high-strength steels with perhaps marginal toughness can be used in actual structures with minimum risk of catastrophic failure. This latter aspect will be covered in the next and in later presentations.

Carbon-containing alloy steels with a carbon content of about 0.40 weight percent seem to offer the best combination of strength and toughness. Greater strengths are available with higher carbon contents, but the toughness is severely reduced, and with carbon contents less than 0.40 percent the desired strength level cannot be obtained. New steel compositions based on carbon-containing martensite are constantly being developed or evaluated, but it is unlikely that any dramatic increases in strength level will be obtained in the immediate future. Some of the newer high strength steels in use today, such as the 5 percent chromium hot work die steels, have in fact been known for many years, but only recently have they been considered for structural applications. This is not to say that there is no need for new compositions or that new steels will not be developed, but rather that increases in strength level will be marginal and improvements will come about in associated properties. Thus steels will be needed with better toughness, low-temperature mechanical properties, weldability, fatigue resistance, corrosion resistance and ballistic protection. These properties may be desired at high strength levels in a greater range of product types and sizes. In many applications lower strength steels will simply be replaced by existing

high strength steels. When this is done we must be certain that the properties other than strength are adequate, so that new failures do not occur.

A somewhat greater chance of attaining substantial improvements in strength lies in the development of new compositions based on carbon-free martensites, such as the maraging steels. Instead of obtaining this strength from the presence of fine particles of iron carbides in the microstructure, these steels depend on the precipitation of exceedingly fine particles of intermetallic compounds, such as Ni_3Ti or Ni_3Mo throughout the microstructure. These steels form martensite under relatively slow cooling, and are quite soft in the unaged condition. Thus, large section sizes may be heat treated, and extensive forming or machining may be carried out. Maximum strength is obtained by a relatively simple aging treatment. A further advantage is that the maraging steels are weldable and may be brought up to maximum strength level by a post-weld reheating.

Currently, maraging steels can be obtained at strength levels up to 300,000 psi. It is hoped that future work will provide still higher strength levels, as well as better combinations of strength and associated properties, such as toughness or fatigue resistance. Improvements in properties are desired over a range of product sizes, including heavy plate, and for maraging type steels at somewhat lower strength levels. This will come about by improvements in melting and fabrication practice, as well as by development of new compositions. Besides modification of the present 18 percent nickel base, new alloys based on lower nickel contents and stainless modifications of the maraging steels are desired.

One area of the technology of high strength steels which holds great promise is the use of thermomechanical treatments. These can be defined as treatments whereby cold work is introduced into the heat treatment cycle of steels, in such a way that improved strength or toughness is obtained. Examples of such treatments include ausforming or hot-cold working, whereby austenite is cold worked at elevated temperatures and quenched so that martensite is formed from cold-worked austenite; zerolling, or the low temperature deformation of metastable stainless steels; and strain aging treatments, whereby quenched and tempered steels are strained and reaged. Each of these treatments is capable of giving substantial improvements in strength. By strain aging alone, or strain aging of ausformed steels, strength levels over 500,000 psi have been reported, although these were accompanied by sharply reduced toughness.

There has been considerable research and development activity in this area in recent years, but as yet there have been no clear-cut commercial or military applications. Partly, this has been caused by the recent appearance of the maraging steels, which has filled the gap in the 250,000 to 300,000 psi strength range. But any substantial further improvement in the strength level of high strength steels will come about by the use of thermomechanical treatments.

One important technological characteristic of thermomechanical treatments has tended to restrict the use of these treatments. This is the fact that the

steel after processing is in the heat-treated, hardened condition. This means that machining will have to be done by grinding or electrospark machining and that heating during welding will tend to destroy the high strength. This restricts the use of thermomechanical treatments to the production of simple shapes, such as wire, rod, strip or sheet, which can be used directly or perhaps used as part of a composite structure; or to the direct production of end items, such as pressure vessels, which can be used after heat treatment with a minimum of final machining.

In the area of thermomechanical treatments, further research is needed in order to understand the underlying factors controlling strengthening. This can be expected to lead to not only improved properties, but also a better chance of obtaining more reproducible properties during processing. Equally important, however, there is a need for technological ingenuity in applying what we already know to the production of actual Army hardware. There is no one steel or processing method which will be optimum, and each application may present its own particular challenge.

In summary, the Army will have a continuing interest in the application of high-strength steels. One facet will be the development of higher strength level steels. Equally important will be the attainment of optimum strength-toughness combinations, perhaps associated with other properties such as stress-corrosion or fatigue resistance. Such steels must be available in the desired product and size range. In many cases existing steels will be replaced by higher strength level steels. This must be done without introducing new problems which will offset the weight advantage gained by the use of higher strength level steels.

MECHANICS OF MATERIALS

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Materials Engineering Division, AMRA

Introduction

Mechanics of materials, within our frame of reference, is the science concerned with the behavior of solid engineering materials involving the interactions among loads, geometrical form of materials, and pertinent properties of materials. The objective of research within this field is to obtain an understanding of behavioral characteristics of engineering materials in order to devise criteria for the various modes of failure and to obtain general principles for design against such failures.

The scope of this area encompasses the overlap between pure materials science on the one hand and classical mechanics on the other. In the past, this area of overlap covered a fairly narrow band. It was possible to obtain material properties quite independently of formulating mechanics theory, while leaving it up to the designer to combine these facets. It is no longer

reasonable to use this approach, however. Modern materials are becoming more complex, and design requirements call for much more efficient utilization of materials, so that it is essential to consider all three elements simultaneously (i.e., the material itself, the environment, and the configuration) if reliable materiel is to be attained.

Within the framework of mechanics of materials, we exclude consideration of structures, thermodynamics, and other branches of mechanics per se. However, research in the behavior of real engineering materials must, of necessity, entail these allied sciences to varying degrees.

The Army has a continuing need for the understanding which is being obtained from research in materials behavior. The direction that future requirements will take is fairly clear. These requirements will be based primarily on the concept of increased mobility for Army materiel. It is the purpose of this presentation to illustrate what the impact of this concept of materiel mobility means in the way of future Army research needs in the area of mechanics of materials.

Relation to Material Needs

There is little that can be added here beyond what the representatives from the Combat Development, Mobility, and Missile Commands have stated regarding future concepts and systems, except to note that the examples given establish the theme for future plans in all weapons and warfare systems. Reliability, mobility, and economy may all have different implications in hardware sense, but to the mechanicist engaged in the study of materials behavior all imply the same goal - a meaningful knowledge of how various classes of materials respond to the environments they must sustain.

In the development of air vehicles, mobility is tantamount to minimum weight, yet without sacrifice of reliability. In this area, the use of composite materials and high strength homogeneous materials presents many challenging problems. Perhaps the most significant is vibration fatigue. Certainly the need for realistic prediction of all aspects of materials behavior is important in aircraft.

Ground vehicles pose different problems to the designer than do air vehicles, but in a sense present the same question to the materials behavior researcher. While the specifics may differ - section sizes, magnitude of loads, dynamic effects, etc. - the possible modes of failure are similar. Fatigue is again a problem, as are other types of fracture.

Missiles and rockets of themselves are of a different nature. The primary goal is to deliver the missile to the target *once*. While this alleviates some problems, it simultaneously raises a myriad of other problems such as ablation and short-time creep due to rapid aerodynamic heating.

Needs of other commodity commands within the Army, although not delineated in this briefing, require the same understanding of materials behavior.

Weapons are required which are lighter; as are munitions. Again, the concept of mobility, coupled with reliability and economy, is the prime factor.

From the requirements of future Army warfare systems grows the obvious needs of higher strength materials. These needs are being met and will continue to be met by the development of new materials such as metals, composites, organics, and ceramics. As these higher strength materials are developed and utilized in various items of materiel, new problems in design are continuously raised. Frequently these problems are solved on a piecemeal basis. Hopefully, the problems are recognized during the development stage and corrected, but not always. Are these problems peculiar to a particular material? Yes and no! Yes, in the sense that the details of materials behavior are intimately tied to the basic microstructure of the material. No, in the sense that, to varying degrees, the possible failure modes of different materials are often similar. Unfortunately, the materials scientist will generally answer yes to such a question; whereas an applied mechanicist will just as frequently answer no. It is to bridge the gap between materials people and mechanics people that mechanics of materials is now recognized as a technical area within the Army's Materials Research Program.

General Considerations Within Mechanics of Material

A striking example of the interplay of materials science and mechanics theory is the area of fracture mechanics. Here classical mechanics are employed in conjunction with material variables to obtain a better understanding of the fracture phenomena.

The design engineer is faced every day with the situation of combining the all-pertinent elements into a reliable design. Unfortunately, there are too few criteria available to satisfy the designer's requirements. Most of those that are available are for quite specialized cases.

Although considerable knowledge has been gained in the development of failure criteria, much of it has been directed toward yield criteria - and this primarily in cases of "well-behaved" materials.

Fracture criteria have been successfully applied to ideal elastic homogeneous and isotropic brittle materials, i.e., the Griffith-Orowan-Irwin criterion. However, even in this case, the procedure is seldom employed in design because of the widely accepted "yield strength approach" to design, and partly due to lack of full appreciation of this criterion.

In the fracture of ductile materials, the situation is not nearly so well defined since flow and necking, which result in a complex stress state, precede fracture; and little is known concerning instability, crack initiation and propagation, and ultimate separation phases of failure. In fatigue fracture (at low stress levels), little or no flow occurs; but cracks nucleate, again resulting in complex stress states, and the situation is even more obscure. Very little is known of how prior damage of a material affects fatigue life even under a uniaxial stress state; under combined loading the

damage effect is virtually unknown. The mechanisms governing the initiation and propagation of fatigue cracks and the final rupture are not understood. Environmental effects on fatigue life require much additional research.

In all cases, the influence of environmental factors is inherent and poses significant further complexities. The effect of temperature, for example, plays a dual role, i.e., it can change the material properties and also superpose added stresses. Time-dependence effects such as shock waves, creep, high strain rates and inertia cut squarely across the entire area of mechanics of materials adding complexity to all aspects of these problems. For example, delay times in flow and fracture phenomena create vast voids in our understanding of failure mechanics.

Criteria for the understanding and accurate prediction of these phenomena are indispensable to ensure reliability, not only because of increasing utilization of high-strength materials in advanced design applications, but also due to the realization that an "infinite life" concept must frequently be sacrificed to achieve weight savings in certain highly mobile military equipment. If a system is intended for a life of one cycle, ten cycles or fifty cycles, the design for maximum efficiency should be for one cycle, ten cycles, or fifty cycles - not for infinite life. Concepts which permit large deformations to occur, provided that fracture or other malfunction does not occur, require much more exacting knowledge of mechanics of materials.

Phenomenological Task Areas

Recognizing that there are many ways of stratifying any technical field, and even more so in a hybrid field such as mechanics of materials, the subdivision we shall present here is merely a bookkeeping device. It is felt that a breakout along the lines suggested below is a reasonable structure for the purpose of analyzing the needs for research in mechanics of materials and is of a format so as to be consistent with the needs of design engineers as well.

We have, therefore, considered the research requirements for mechanics of materials to be included in the following seven phenomenological task areas:

Elastic	Fatigue
Yield	Creep
Flow	Wear
Fracture	

These categories are not mutually exclusive nor are they necessarily all inclusive. They do, however, serve to delineate areas in which we feel the most pressing problems exist. It may be helpful to suggest a little further refinement of our views of the field of mechanics of materials. In addition to the categorization suggested above, there are other factors to be considered. The table below illustrates this.

LEVEL	I	II	III	IV
CATEGORY	Phenomena	Influencing Factors	Classes of Material	Objectives
	Elastic Yield Flow etc.	Time Temperature etc.	e.g. Metallics Composites etc.	Design Criteria Experimental Tech. etc.

In considering any one phenomenon, it is necessary to look into the effects and implications of these other factors. The level of categorization does not imply importance of the categories, but rather provides a method of recognizing the existence of factors.

Needs for Mechanics of Materials Research

It is not realistic from our point of view to list, in a specific way, problems requiring research in mechanics of materials. Those of you involved in this area recognize the problems as well as we. You also realize that the Army is interested in making headway in this area. We hope, however, that by spending a short time on discussing research requirements it will lend a flavor of mutual developmental-research implications to the proceedings.

What follows are thoughts for research work in the various phenomenological task areas. These thoughts are not presented as programs or projects within materials research. They are guidelines which the Army is using in assessing research.

These thoughts essentially represent gaps in the state-of-the-art. Or perhaps more accurately, those voids in the state-of-the-art which pose barriers to the attainment of efficient items of materiel.

a. Elastic

Recently more powerful techniques, both theoretical and experimental, have become available which have provided significant advances in the understanding of elastic phenomena. However, many important gaps still exist. Some of these are three-dimensional effects, anisotropy of materials, dynamic effects, thermal loading, high stress gradients (stress couple theory), individually as well as in combination.

b. Yield

Currently available yield criteria are adequate for only well-behaved materials. In applying a criterion to a material, it is seldom easy to decide as to which, if any, of the available criteria would be most appropriate. The effects of complicating factors such as time, temperature, metallurgical interaction, anisotropy, etc., are not well understood, if at all.

c. Flow

In the area of flow the situation is quite obscure. There is considerable question as to what rule or rules govern flow. The effects of such complicating factors as noted under yield above are virtually unknown.

d. Fracture

Criteria for the fracture of ideally brittle materials are available and reasonably reliable. In materials exhibiting any toughness, however, none of the criteria are fundamentally sound nor sufficiently accurate. The question of ductile fracture is relatively unresolved. The relationship of creep to fracture (i.e., delayed fracture, including long-time creep) is a major barrier.

e. Fatigue

The phases of fatigue failure have been recognized but are not understood. The collection of endurance limit data per se is not of any real value to the understanding of fatigue. The real problems lie in the finite life range where our knowledge is the most sparse. There is limited empirical correlation of fatigue to fracture mechanics concepts and, although various damage concepts have been proposed, none is satisfactory.

f. Creep

While there has been some progress in the mathematics of linear viscoelasticity, the various spring-dashpot models do not describe the actual processes. All available knowledge of time-temperature interdependency is empirical. Future advancement of the science will depend on finding out more about internal friction on the micromolecular level. The rearrangement of slip planes is a dominant factor in true (i.e., long-term) creep. Short-time creep poses problems which can be solved at the present time only by testing.

g. Wear

The present situation is almost entirely empirical. Criteria for the various types of wear do not exist, nor is the process of wear understood. Considering the general phenomena of wear (including ablation), consideration must be given not just to the abrasion problem, but also to thermal effects and fluid behavior.

The nature of the required research in this area is primarily of a "basic" nature, at least in the sense that it applies to a relatively broad range of existing and potential classes of problems. To reiterate, the goal of this research is to achieve a more general understanding of the behavior of solid engineering materials. It is important to consider what the ultimate objective is.

The proper direction for such research must be predicted on the recognition of significant gaps in the current state-of-the-art. Before it is reasonable to formulate specific details of research, it is necessary first to assess our present position and establish general (but not vague) goals.

It is not the intent of this document (nor should it be) to establish specific approaches to the solution of problems. The best approaches will be those that yield valid improvements, increased generalities in theories, and the establishment of new theories. These approaches will depend primarily on the individual researcher's experiences and concepts. To attempt to influence these other than in the sense of providing broad guidance would result in a loss of efficiency.

CORROSION RESEARCH PROBLEMS

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Introduction

The need for protection against the ravages of corrosion (which is intended to encompass erosion and high-temperature oxidation) applies to all Army materiel including weapons, combat vehicles, missiles, launchers, transporters, aircraft, and a wide variety of other support equipment. It is the Army aim to acquire scientific knowledge to provide new materials and processes to reduce corrosion losses which result in disabled or malfunctioning equipment. Losses due to corrosion can represent substantial costs, which must be reduced. The wide extremes of climatic conditions encountered in modern warfare and the fact that many military items consist of complex assemblies of different materials point up the need for maximum corrosion protective treatments to ensure serviceability of equipment at the required reliability level in combat. Army interests in basic and applied corrosion research are aimed at two principal general areas: one, the further elucidation of fundamental corrosion reactions, and two, the development of improved protective materials and processes to meet serviceability and reliability demands of Army materiel.

Fundamental Corrosion Phenomena

Certain theoretical concepts are available upon which we base our present understanding of corrosion phenomena. Much more needs to be learned, however. For example, the fundamental chemical reactions occurring in electrolytic media, and the solid-state reactions occurring between metals and solid gas reactants are not completely understood. The concentration of reactants and the permeability of thin film corrosion products to ions needs additional study. Further understanding of corrosion mechanisms will lead to better technical understanding of the factors controlling specific corrosion processes.

Research on corrosion mechanisms through basic electrochemical studies of electrode kinetics should lead to a more fundamental understanding of passivity and inhibition phenomena as well as to more enlightenment concerning the origin of pitting.

Research on the effect of stress and environment on the insidious cracking of otherwise ductile metals is vitally important, particularly with the increasing utilization of the Army of ultrahigh-strength structural alloys. Mechanisms of stress-corrosion cracking are not yet fully rationalized. Much of the theoretical knowledge provides explanations for cracking without providing guidelines for control. Explanations have been advanced based on fracture mechanics concepts and surface energy changes in specific environment. Further research is required to test the validity of these and other newer concepts. The development of rapid, accurate and reproducible testing techniques would contribute significantly to advancing the study of stress-corrosion cracking.

Galvanic corrosion and its prevention will continue to be important to the Army since modern military equipment requires utilization in single assemblies of combinations of metal components having different electrochemical characteristics. Injudicious coupling of dissimilar metals in equipment which encounters environmental extremes has led to many premature failures. Additional fundamental information on galvanic behavior is needed for metals which are less commonly used now but which may find more widespread military use in the future, e.g., beryllium, uranium, columbium, zirconium, molybdenum, when coupled to each other or to the more commonly used engineering metals.

There is an ever-increasing need for materials which will satisfy the hot-strength requirements in structural components of certain Army equipment. The refractory group metals and their alloys are the prime candidate materials. For applications above 3000 F tungsten offers the most promise when satisfactory coatings for oxidation control can be developed. The fundamentals of the oxidation of tungsten are exceedingly complex and alloying to improve oxidation resistance is not hopeful as yet. Further intensive research is needed in order to develop a unified theory of the overall tungsten oxidation process.

The expanding use by the Army of ultrahigh-strength steels with their high susceptibility to hydrogen embrittlement points up the need for further research on hydrogen overvoltage control to inhibit hydrogen adsorption during chemical and electrochemical processing of the high-strength structural metals.

Protective Systems

Principal reliance for the protection of military equipment under conditions of storage, shipment or field use is placed on protective surface treatments or coatings. For protection against aggressive ambient environments and against galvanic, stress, fretting, and high-temperature corrosion, various coating systems are employed including electrodeposited metals, diffusion coatings, inorganic coatings, and organic coatings. Frequently, the best coatings are limited in their use to certain metals or are unsuitable for use under the operating conditions or environments encountered by modern military equipment. Virtually every protective system, thus, demands periodic scrutiny. Consequently, continuing improvements of common protective

coatings and application processes are required. New or improved protective systems are constantly sought for specific uses. For example, further research is needed for development of alloy electrodeposits with improved environmental and high-temperature corrosion resistance. The development of economical commercial processes for depositing "refractory" metals such as molybdenum and tungsten from aqueous electrolytes and fused salt baths is needed. The extension of chemical and electrochemical conversion coating processes to metals such as beryllium, columbium, and titanium could be highly useful in enhancing the range of application of these metals. The Army also has need for development of intermetallic, ceramic and cermet coatings as more permanently useful high temperature and erosion-resistant coatings.

Army research on corrosion and protective systems is carried out at several laboratories of the major subordinate commands of the U. S. Army Materiel Command as well as at the U. S. Army Materials Research Agency. A portion of this research is sometimes done under contract. The major program of basic research on corrosion is normally managed by the Army Research Office-Durham, under whose aegis contracted research projects are carried out at universities.

CERAMIC MATERIALS

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The Army Ceramics Research Program

For the purpose of this meeting, it is convenient to describe the Army's ceramics activities in terms of functional rather than material categories. For military application and especially weapons development, the following subdivisions seem to be most appropriate:

1. Ceramic Processing
2. Coatings and Cermets
3. Design with Ceramics
4. Physical and Optical Ceramics
5. Refractories
6. Structural Ceramics
7. Thermal Insulators and Ablators

Ceramic Processing

In studying those ceramic processes which precede consolidation of particulate materials into a bulk, some tentative conclusions have been reached as to the scientific research and industrial development which would be most helpful in the immediate future. The four points listed below have some

bearing on the future development of ceramic processes essential to improve reliability and uniformity of ceramic materials and parts required for advanced military systems.

a. Increasing emphasis will be placed on ultrahigh purity, controlled composition, and submicron-particle-sized ceramic powders intended for sintering and hot pressing.

b. Because of inherent difficulties in the uniform compaction of fine particles, greater attention will be given to the control of size-shape distribution and internal particle arrangements in granules.

c. The most critical scientific limitation in powder technology is our inability to identify and characterize significant particulate variables. Research in identifying and measuring better criteria for powders and agglomerates will have an important influence on future production and use of ceramic raw materials.

d. Also needed is the development of instrumentation and techniques, such as computer programming, for identifying and eliminating those ocassional deviations in structure and composition of a powder mass which produce isolated voids and other defects in finished ceramic bodies.

Coatings and Cermets

Methods of processing coatings should be improved to provide more predictable properties, better bonding to the substrate, and a greater degree of tailoring of coating compositions and structures to arrive at specific properties. The next few years will be spent consolidating present knowledge and explaining basic processes and properties of ceramic coatings.

The field of cermets seems to need a reappraisal in the light of recent developments in the theory of composite materials. The main difficulty seems to lie in the response of interface phenomena to stress.

Design with Ceramics

Modern design methods and concepts are developed for and applied to ductile materials. When brittle materials are incorporated in engineering systems they are seldom integrated, load-carrying structural members, but serve only a highly specialized purpose.

With the necessary use of materials in extreme environments and the intensified trends to assign functional and structural duties to the same part, brittle ceramic materials with special property spectra have become increasingly attractive. However, the problem of their structural incorporation into a system becomes acute. This is the reason why a study of design with ceramics cannot be excluded from a research program for ceramic materials, and why the ceramist himself has to have a feeling for design parameters and concepts.

Physical and Optical Ceramics

This area of ceramics materials research is characterized by the consideration of materials for use with optical radiation. In the broad sense optic radiation includes not only visible light but ultraviolet and infrared spectra as well.

At present we are limited in our understanding of the nature of the effects of these materials factors in optic interactions. This is primarily due to the relatively dominant role taken by small concentrations of either defects or dopants in these interactions. Heretofore the optic materials technology was not concerned with such minor concentrations of defects; it now appears that no advancement in the state-of-the-art can be attained without a thorough respect for these factors.

Refractories

Military system requirements have changed considerably over the years. As component temperatures have increased, ceramics have been periodically selected, evaluated, and discarded owing to a combination of their brittle behavior and the ability of the designer to compromise in order to permit utilization of the more familiar metals. The situation relative to military system needs is fast reaching the point where the compromises necessary to permit utilization of the familiar metals will also compromise system performance to an unacceptable degree. The rate of industrial development and progress in refractories is high, higher in fact than it has ever been. Unfortunately, however, the character of industrial application is so far removed from weapon systems needs that this present rate of development generates little confidence that military needs will be satisfied without a concerted effort.

It is difficult to predict the ultimate property levels attainable in refractory ceramics because of the tremendous lack of pertinent information. While many properties have been measured and reported, in almost no case has relevant data been reported on sample purity, stoichiometry, grain size, distribution and orientation, porosity, or particle surface chemistry.

Certain problems are common to all ceramic materials, namely, lack of reproducibility, nonuniformity of microstructure, and brittleness. It is quite likely that great improvements will be made in the reproducibility and microstructure. However, advances are expected in design technology for brittle materials which should affect the applications of refractory ceramics. In addition, the application of refractory ceramics is being attempted through the development of a design technology for brittle materials.

Structural Ceramics

From a long-range point of view, continued efforts to understand fracture phenomena in single crystal ceramics will provide the key to imparting a limited degree of ductility to polycrystalline aggregates. For the more immediate future, the payoff for the utility of ceramic materials will come from: (a) utilizing prestressing techniques such as thermal or chemical

conditioning to raise the fracture stress of polycrystalline ceramics; and (b) increasing the strength of polycrystalline ceramics by controlling the microstructure through a better understanding of processing variables.

Some of the more significant problems that are being considered include purity and particle-size control of raw materials, the effects of atmosphere and temperature on stoichiometry and structure, the role of grain boundaries and the effects of surface treatment on mechanical behavior. The relation between microstructural features such as grain size and distribution, crystal structure, texture, crystal defects, impurities in the grain boundary and mechanical behavior are also being studied.

Thermal Insulators and Ablators

Components of modern defense systems may be exposed to temperature environments far in excess of the melting points of the best refractory materials. The protection of structural and functional parts in such environments is only possible with materials providing certain automatic cooling provisions. For ceramic materials, the most feasible cooling provisions are: heat-sink, radiative and ablative methods. A combination of all these is often used most successfully. Because ceramic materials are poor heat conductors and have little thermal shock resistance, they are generally of little use for heat-sink applications. However, beryllium oxide and graphite and certain carbides at high temperature are good heat conductors, and may therefore be applicable for heat-sink cooling under certain conditions.

Analysis of Military Requirements

Many major military systems, such as communications and data processing, electronic warfare and surveillance, and missile and weapons coordinates, are critically dependent on the electronic components which are building blocks of this equipment and systems. One of the most important trends that has developed in military electronics equipment design is that of microminiaturization, whereby assemblies of thousands of parts performing hundreds of circuit functions may be packaged in a volume of less than a cubic inch.

Some of the problems related to electronic devices are, for example, the need for heat removal in equipment miniaturization by thermoelectric cooling devices or heat-sink materials such as beryllia and design against radiation effects from exposure in a nuclear weapon environment or in outer space.

The interest in ceramics for missiles is naturally concentrated in the area of refractories, thermal coatings and ablating materials. Higher flame temperatures, longer firing times, and more corrosive-erosive exhaust products necessitate a steady effort to develop improved nozzle materials. Thermally stable and shock-resistant bonds of refractory coatings to heat-sink substrates is of great importance. Often the development of new materials must be placed in phase with the application of new cooling methods, and designer, engineer, and ceramist have to coordinate their efforts. Ablative materials with low radar cross section and high electromagnetic transmissivity must be

developed. Materials for blast deflectors and flame shields are far from being optimized. Protective coatings have to be developed for antimissiles which travel very fast and under extreme conditions at low altitudes. Thermal linings for blowpipes for thrust vector control are not yet available.

Other requirements for ceramic materials lie in the field of guidance and control. Ceramic-metal bonding for gyro components has to be improved to increase accuracy and reliability of the missile system.

The hardening of warheads against antimissile defense is another field where ceramists are able to make major contributions. Protection of missile warheads against X-ray kill without considerable increase in total weight may be achieved by modulation of the ablative coating. The study of damage mechanisms by radiation shocks becomes increasingly important.

There is a requirement for increased activity in optical materials and technology. This is due to the increased use in numerous military roles of a wide variety of modern optic devices. These newer uses, for which essentially no materials technology exists, include both weaponry and protective devices. Critical problems exist in the optic materials which are to be used in the strong optic field of laser devices; this includes both viewpoints - that of using the laser radiation such as in optic systems, and that of protecting eyes and vision devices. In addition, the entire field of semiconducting and conducting glasses and optical materials is expected to solve numerous application problems in modern optic devices.

Ceramics are not generally considered for ammunition for military systems. One exception is the use of carbide projectiles and cores, specifically those of tungsten carbide. These carbides are very hard and quite dense, and consequently perform as good penetrators for defeating armor. Carbides, like most ceramics, have processing procedures which are not applicable to high-speed production of ammunition, are brittle in nature, and possess low impact strength. The properties of brittleness and low impact strength can be overcome by establishing appropriate design criteria. On the other hand, fabricating carbides into shaped components in a high-speed operation presents a major obstacle, and research in this area is needed.

Ceramics are important in producing ammunition and components, and their further development will have significant effect on future systems. One of the biggest uses for ceramics is in cutting and grinding tools. In most production machining operations, the factors which limit the production rate is the machine tooling. Development of tooling which has desirable properties for ultrahigh-speed machining will greatly increase production and will probably result in significant cost reductions. Casting also plays a significant role in the production of components. Since 1946, great strides have been made in the foundry field through the application of ceramic molds. There is currently an interest in metals and alloys which have high strength-to-weight ratios, for example, magnesium-aluminum and magnesium-lithium. These alloys are quite reactive in the molten state and ceramic molds appear to be the best mold candidate material.

There is a requirement for ceramic materials in the area of high temperature coatings, gun tube liners, refractories and armor materials.

High temperature coatings and ceramic liners have desirable resistance to thermal shock, erosion and oxidation when exposed to the erosive gases of weapon firing systems. However, the severe shock load accompanying the erosive gases generally results in fracture of the ceramic. Ceramic bodies for electrical insulation of electrical firing systems also experience failure under similar shock loads.

Other requirements for ceramic materials are in the area of military specifications. Lack of military specifications for processing ceramic materials results in materials of inconsistent properties.

There is an urgent requirement for lightweight armor systems for the protection of personnel against bullets and fragments. In particular, high strength-to-weight ratio materials are required. Improvement in the effective strength level of ceramics would be a prime requirement. Special armor systems are contemplated which place the requirement of optical transparency on an equal basis with the required ballistic protection. In other systems composed in part of ceramics, the additional requirement of flexibility is desired, even though the system is composed of brittle members.

The requirement that the ceramic component be compatible with other materials is often taken for granted, but in good design this factor must be considered. The importance of this aspect for armor requirements is significant since personnel armor systems are multicomponent in nature and metals, plastics and fabrics as well as ceramics may find use in end items.

COMPOSITE MATERIALS

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A composite material may be defined as one consisting of two or more dissimilar materials working together to yield a new material whose properties are different in scale and kind from those of any of its constituents. The limitations of single materials have intensified interest in composite materials with their great number of possible constituents. The Army's requirements for high strength, lightweight structures for its missiles, small aircract, and vehicles are self-evident. The current war in Viet Nam further amplifies these requirements, with special emphasis on improved high temperature turbine blades for aircraft jet engines.

There are many types of composites in various stages of development. One type which is especially promising is the whisker-reinforced class of materials. Whiskers are ultrahigh-strength micron size single crystals. Figure 1 shows some typical "C" type alumina whiskers.

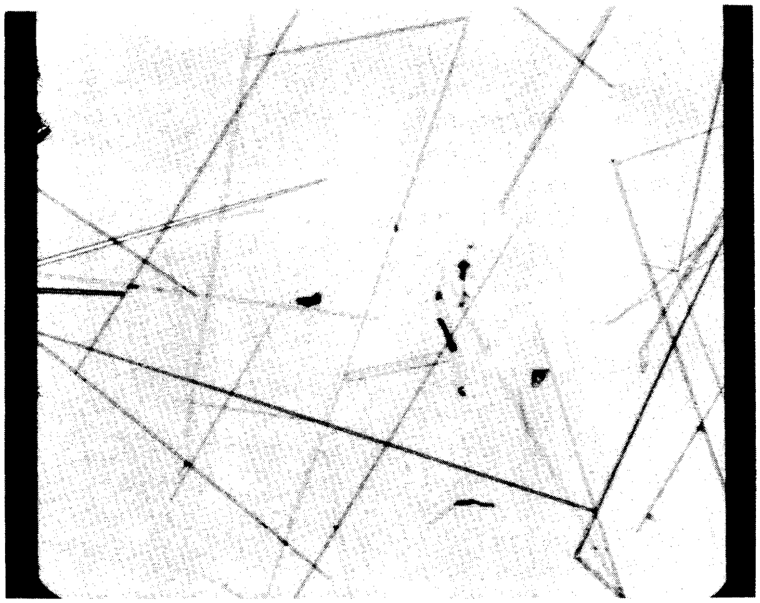

Figure 1. ALUMINA WHISKERS. "C" TYPE, WITH MAXIMUM DIAMETER ABOUT $7\frac{1}{2}$ MICRONS. L/D RANGE 350-380. MAGNIFICATION 55X

19-066-1500/AMC-65

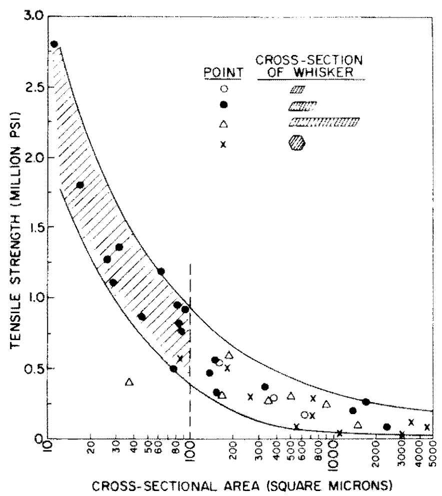

Figure 2. RELATION BETWEEN TENSILE STRENGTH AND CROSS-SECTIONAL AREA OF αAl_2O_3 WHISKERS

Courtesy of General Electric Space Sciences Laboratory

19-066-1207/AMC-64

Figure 2 shows the tensile strength of aluminum oxide whiskers as a function of cross-sectional area. This type of curve has generally been observed for a wide variety of materials in whisker form and is attributed to their increasing perfection with reduction in size. Aluminum oxide whiskers are particularly attractive as strengthening agents because they have low density, very high modulus, high-strength retention at elevated temperatures, high melting point and chemical stability.

Table I shows the effect of temperature on the strength of an aluminum oxide whisker having a room temperature strength of 2,000,000 psi. At 3400 F only 380 degrees below its melting point, the strength is still 200,000 psi.

Table I

Temperature (degrees F)	Tensile Strength (psi)
R.T.	2,000,000
1200	1,500,000
2000	1,300,000
3400	200,000

Material Al_2O_3; Density 3.97 g/cm^3; Melting Point 3780 F.

The potential of aluminum oxide whisker-reinforced metals is shown in Figure 3. These projections are based on (a) 50 volume percent whisker additions, (b) alumina fibers having tensile strengths of 1,000,000 psi and elastic moduli of 60×10^6, and (c) good bonding between matrix and whisker with its associated effective shear load transfer from the former to the latter. It can be seen that the strength-to-density ratio of plastics can be doubled over the same temperature range. This ratio is also more than doubled for metals in the temperature range 1000 to 2000 F, while operating temperatures can be raised over 1000 F.

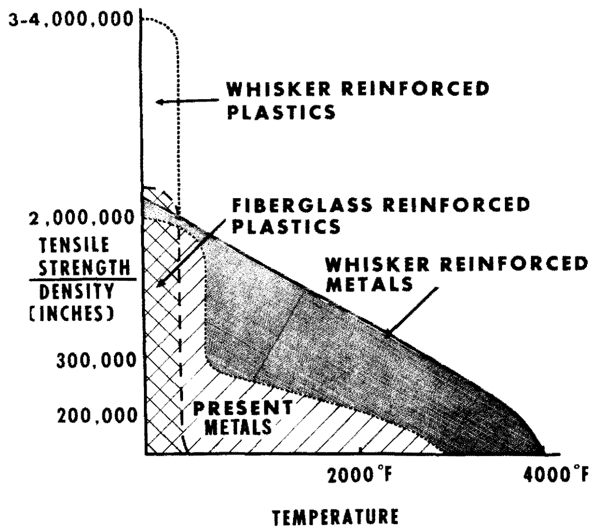

Figure 3. POTENTIAL OF Al_2O_3 WHISKER-REINFORCED MATERIALS COMPARED TO PRESENTLY AVAILABLE MATERIALS
Courtesy of General Electric Space Sciences Laboratory
19-066-1206/AMC-64

Recent experimental data verify the fact that Al_2O_3 and other whiskers significantly strengthen metals and plastics when all of the criteria for reinforcement are met. These criteria are:

1. The composite should contain a high strength, high modulus fiber in a weaker, low modulus matrix.

2. The volume fraction of whiskers must be great enough to provide reinforcement.

3. There must be sound, resilient bond between the fiber and matrix, for effective load transfer.

4. The fiber must be chemically and physically compatible with the matrix.

5. The fibers should have tapered or rounded ends to reduce stress concentrations in the matrix at these points.

6. The fiber must be stable at room and elevated temperatures and retain a large proportion of its strength at high temperatures.

7. The fibers must be properly oriented and distributed in the matrix for optimum load transfer.

In addition, there is the general requirement that alumina and other whiskers be available in large quantities at low cost and that fabrication techniques be developed for incorporating and orienting them in and bonding them to many types of matrices. Figure 4 shows the results obtained by

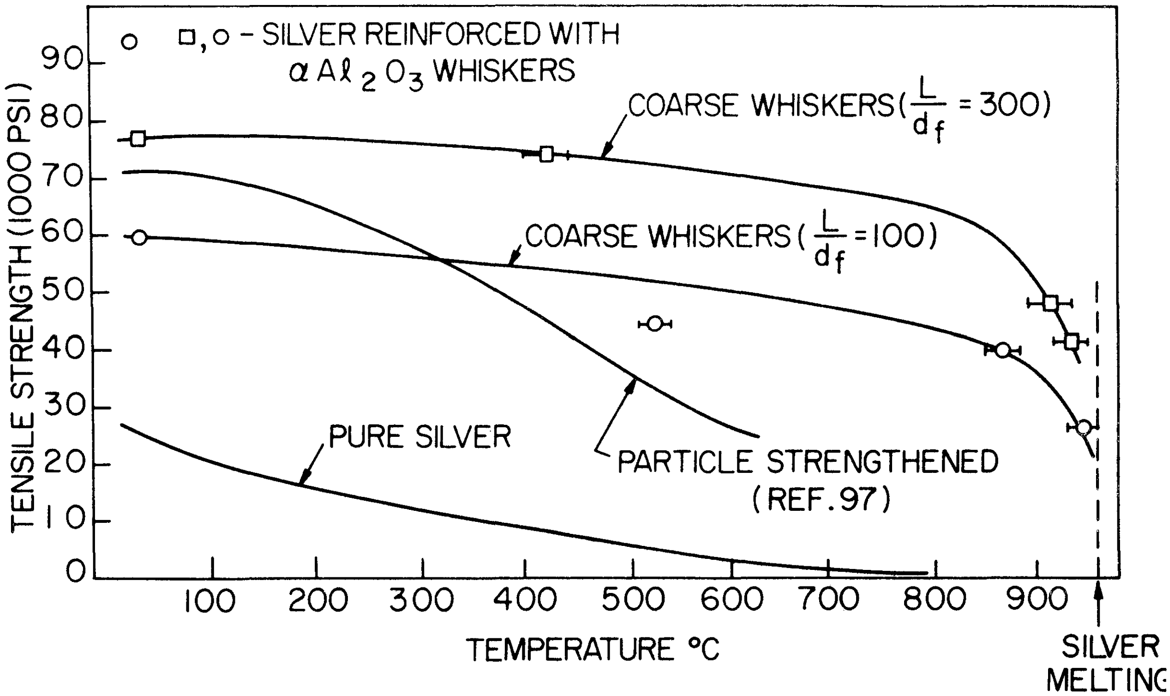

Figure 4. TENSILE STRENGTH OF SILVER AND SILVER STRENGTHENED WITH Al_2O_3 PARTICLES AND WITH Al_2O_3 WHISKERS AT VARIOUS TEMPERATURES (From Sutton and Chorne, Ref. 1)
19-066-1448/AMC-65

Sutton and Chorné[1] of General Electric Company under a Navy Bureau of Weapons contract when silver was reinforced with 20-40 volume percent alumina whiskers having various length/diameter ratios. The high temperature strength of the whisker-reinforced composites is remarkable when compared to the unreinforced metal. At 930 ± 10 C (98 percent of the melting point of silver) strengths of 25,000 have been measured.

Sutton and Chorné have also reinforced aluminum with 35 volume percent alumina whiskers to get a composite tensile strength of 161,000 psi.

Future Plans

Effort will be directed at extending the promising results obtained with small specimens to larger structural composites of common engineering matrices such as aluminum, steel, and nickel and epoxy resins.

The following areas are mentioned as essential to the attainment of this objective.

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[1] *SUTTON, W. H., and CHORNÉ, J. Development of Composite Structural Materials for High Temperature Applications. General Electric Company, 17th Quarterly Progress Report, U. S. Navy Contract NOw-64-0560-C, September 1964.*

Whisker Production

A greater supply of high-strength whiskers is needed. To this end the Army has supported very promising research with Lexington Laboratories. It is hoped that this will provide the stimulus for further industrial development of whisker growth processes. Recent announcements by industry are encouraging. For example, the Carborundum Company recently announced the availability of high-strength, whisker-like boron nitride fibers. They can also produce silicon carbide whiskers on a tonnage basis. Thermokinetic Fibers Inc. produces various types of whiskers and indicates that production can be expanded to 100,000 lb/yr with a corresponding price drop if there is sufficient demand. Other organizations such as General Electric Company produce whiskers to meet their internal research and development requirements.

Whisker Properties

It is planned to extensively study the room and elevated temperature properties of the whiskers, such as Al_2O_3, SiO_2, Si_3N_4, and boron. Since whiskers will be the key elements in whisker composites, their short-time and long-time properties must be fully known and understood. Specifically, additional data are needed on their identification, room and elevated temperature tensile strength, elastic constants, creep, stress rupture and fatigue strength. Because of their extremely small dimensions, they are very difficult to handle. Therefore, new techniques must be devised for manipulating and testing them.

Whisker Matrix Bonding

The wetting and bonding of whiskers such as Al_2O_3 and Si_3N_4 and SiC to various metals, such as nickel and aluminum, and plastic epoxy matrices will be determined by sessile drop tests in various atmospheres. The effects of selected metal additives will also be determined as will the optimum amounts for maximum bonding. The long-term interfacial reactions between whisker and matrix will also be investigated. As new whiskers become available, their compatibility with various metals and plastic matrices will be evaluated.

While plastics generally wet and bond to whiskers much more readily than metals, their bonding characteristics will also be quantitatively determined. The overall objective is to make available a very wide range of possible whisker-matrix combinations to meet a variety of operating requirements.

Whisker Composite Fabrication

Fabrication studies will be continued and expanded. Maximum strength composites require maximum additions of completely aligned, uniformly distributed whiskers to a suitable matrix. Whisker composite development involves many scientific disciplines and will greatly benefit from the coordinated efforts of metallurgists; ceramists; physicists; chemists; mechanical, chemical, and textile engineers. The filamentary nature of whiskers makes them particularly amenable to the textile technique of carding, spinning, weaving, and felting. Parrat of the Ministry of Aviation in England has fabricated whisker-reinforced composites by semi-automatic processes from complete furnace batches of micron whisker wool. We would like to progress further in

this area by developing fully automated fabrication processes. To this end studies will be directed at (1) the grading and alignment of whiskers by various techniques such as dispersion in liquid media, filtration, and vibratory separation; (2) coating of whiskers by vapor phase reactions and electroplating, and (3) incorporation in and bonding of whiskers to metal matrices by powder metallurgical techniques, liquid metal infiltration, followed by rolling and/or extrusion.

Whisker Composite Properties

The ultimate test of these composites is their performance under the desired operating conditions. Therefore, all experimental composites will be evaluated for their room and elevated temperature mechanical, chemical (oxidation resistance) and thermophysical properties.

Whisker Composites by Unidirectional Solidification

Whisker-reinforced composites can also be made by the unidirectional solidification of eutectic alloys. In these systems, the reinforcing phase solidifies as whiskers or platelets which are oriented, distributed in, and bonded to the matrix. There appears to be a "built-in" compatibility between whisker and matrix.

Several high temperature binary eutectic systems have been investigated under a contract with United Aircraft Research Laboratories. The best results were obtained with a Ta-Ta_2C alloy which exhibited a room temperature strength of 150,000 psi and a strength of 52,000 psi above 2000 F. The Army is currently supporting additional research in this area at Lehigh University aimed at improving the properties of lightweight alloys.

Much has been learned from the study of model binary eutectic systems. Future interest will be directed at applying this knowledge to useful engineering alloys.

CHAPTER VI

Future Materials Application Aims

The use or application of materials and the research that centers around this effort is an essential part of the total materials research effort. Programs that further the results of scientific research and, under advanced technology studies, develop useful engineering materials, continually produce useful data for designers and engineers. The testing and control through specifications and standards round out the assignment. As in the previous chapter, the aims of future effort are presented. Mr. Arthur F. Jones, Chief, Materials Technology Division, AMRA, served as Moderator for seven presentations by the AMRA staff. The confidential paper on Organic Materials is included in Part II of these Proceedings.

CASTINGS RESEARCH

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Every major weapon system requires cast metals. The Army uses every type, shape, and alloy in equipment ranging from gun mounts to missile components. Increased emphasis is placed on lightness and air transportability. Thus the strength-weight ratio is becoming more important and Army research goals in cast metals inevitably involve efforts to improve casting reliability, increase the strength level, and reduce the safety factor. The actual practical research goals are usually expressed by a table of target properties to be obtained at some future date. For example, Table I is a basic table of target properties for steel castings. The research goals in respect to other alloys such as aluminum have also been expressed in a similar fashion. A second important emerging research goal involves the use of malleable iron and ductile iron shell. The fragmentation mechanism must be understood so that manufacturing procedures can be set down that will guarantee fragmentation characteristics of shell material. It is proposed that certain metallurgical variables can be correlated with fragmentation. This is a unique separate problem that will not be discussed here.

Table I enumerates castings research goals that are being fulfilled by the castings research program. The program is divided into seven major tasks: Task A. Solidification; Task B. Fluid Flow; Task C. Mold Problems; Task D. Alloy Development; Task E. Molten Metal Reactions; Task F. Processing of Cast Structures; Task G. Specifications and Standards. Work is going on in most of these areas, but the most important task is represented by research on solidification. It is proposed that the major upgrading of cast metals can be accomplished through developing an understanding of the solidification process.

Therefore, instead of considering every task in its broad sense, let us examine the solidification variables in some detail to show the results that have been obtained. The results are represented not for themselves alone, but as a means of indicating the great opportunities for improving casting quality by way of solidification control.

Table I. TARGET PROPERTIES HIGH-STRENGTH, TOUGH, SHAPED STEEL CASTINGS

Max. Crit. Section Size (in.)	Yield Strength 0.2% Offset (psi)	R.A. (%)	Elongation (%)	Charpy V-Notch Impact Energy -40 F (ft-lb)
3	170,000 - 179,999	25	14	24
	180,000 - 189,999	24	13	22
	190,000 - 199,999	23	12	20
2	200,000 - 209,999	22	11	19
	210,000 - 219,999	21	10	18
	220,000 - 229,999	20	9	17
1	230,000 - 239,999	19	8	16
	240,000 - 249,999	18	7	15
	250,000 - 259,999	17	6	14

The solidification variables are best studied in unidirectionally solidified material where all of the dendrites are lined up in the solidification direction. Figure 1 shows a unidirectional steel. The general aligned structures are brought out by an acid etch, but the details of structure are most visible in Figures 2 and 3 which are a series of macros transverse and longitudinal to the chill surface of the casting. The cruciform configuration of the dendrites is clearly visible in the set of transverse macros, while the longitudinal photos indicate that the dendrites are columnar and have a total length that must be measured in inches. Such photos can be employed to reconstruct the dendrite. Figure 4 is especially helpful in this regard; two surfaces have been polished and etched. The top surface is parallel and the bottom perpendicular to the solidification direction. The dendritic markings and the line of join between the two surfaces form measurable angles that establish the location and orientation of the principal dendritic growth planes.

It must be remembered that the foregoing figures on dendritic morphology are also crude representations of microsegregation, for the etching procedure depends on chemical variation in the dendrites. A more sophisticated method of looking at the local chemical variations is to employ the electron-beam microprobe. Figure 5 shows samples for microprobe examination. Microprobe scans were taken along various directions. An interesting example is a scan at 45 degrees from the axis of the dendritic cruciform. The results of such a scan are shown in Figure 6. The abscissa is distance along the scan and the ordinate is Ni, Cr, Mo content, etc. The local chemical variations are great. The major problem can now be stated. How does one reduce the amplitude and frequency of these chemical variations? The amplitude can be reduced by conducting a high-temperature diffusion homogenization treatment. Such a

treatment yields a marked improvement in mechanical properties. In Figure 7 mechanical properties are plotted versus distance from the chill. The basic heat treat properties of this unidirectional 4330 steel are shown by the dashed lines while the properties after homogenization are represented by the solid lines.

An alternate procedure is to reduce the frequency that is to reduce dendritic spacing by the addition of grain refiners to the melt. Figure 8 demonstrates the results of grain refining. Once more mechanical properties of unidirectional steel are plotted versus distance from the chill with and without grain refining; and once more properties are increased.

A third procedure is to simultaneously reduce amplitude and frequency by the method of undercooling. Successful undercooling experiments can alter the dendritic pattern and microsegregation, as demonstrated by the macro of an undercooled sample shown in Figure 9. Experiments of this type are not sufficiently advanced, as yet, for examination of mechanical properties.

The current position of solidification research has been outlined. The foregoing demonstrates that a firm foundation has been established for improving mechanical properties of castings, and also for improving the mechanical properties of forged materials. There is a definite interrelationship between microsegregation and dendritic size and mechanical properties. If these first two independent variables are controlled in a favorable way, then the dependent variables of mechanical properties will be enhanced. One of the major current castings research objectives is to increase mechanical properties by way of altering dendritic morphology or by upsetting the pattern of microsegregation. Possible methods are homogenization, grain refinement, undercooling, or by designing non-segregating alloys. These current major research objectives apply not only to steel, but to other casting alloys and to ingots that are to be forged.

At this date some of the solidification results have been applied in a meaningful way to the manufacture of castings. The unidirectional turbine blade and the unidirectional breech ring are just two examples. Over the next year some of the above techniques are to be applied to manufacture of cast armor and selected tank castings. However, the basic experiments on solidification will continue in order to meet mechanical property goals and strength-to-weight requirements.

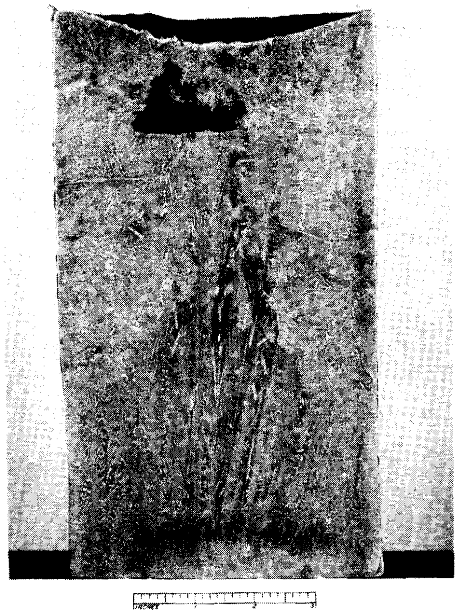


Figure 1. CASTING 69 - UNIDIRECTIONAL SOLIDIFIED COLUMNAR GRAIN. HIGH-STRENGTH STEEL CASTING.
19-066-1529/ORD-62

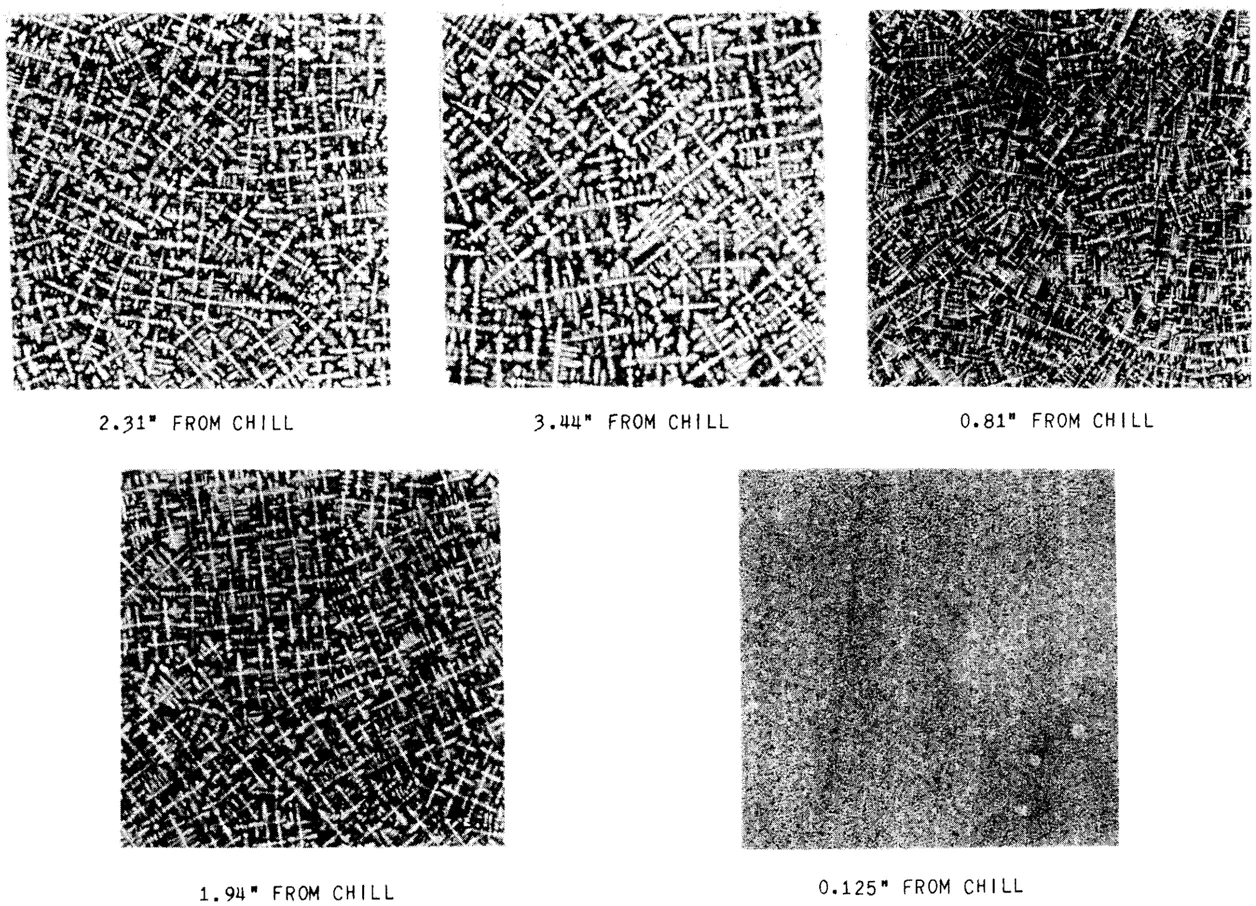


Figure 2. MACROSTRUCTURE PERPENDICULAR TO THE DIRECTION OF SOLIDIFICATION (STEAD'S REAGENT). 6X.
19-066-1495/AMC-63

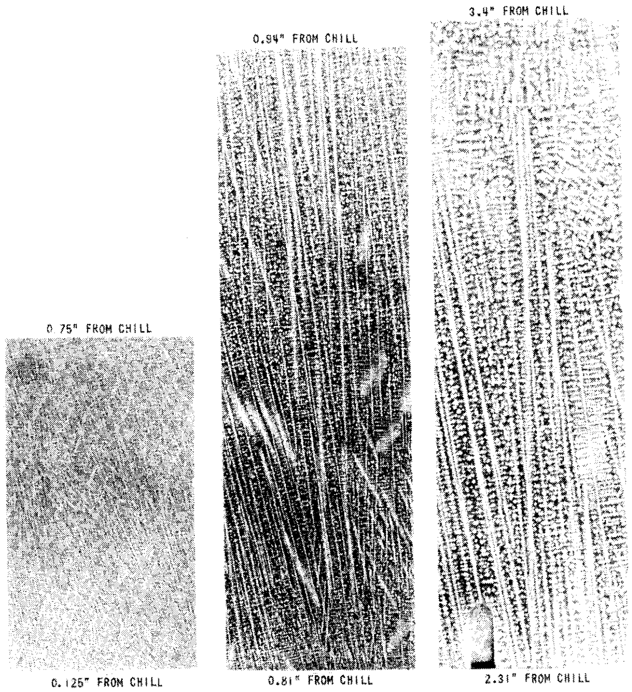


Figure 3. MACROSTRUCTURE PARALLEL TO THE DIRECTION OF SOLIDIFICATION (STEAD'S REAGENT). 6X
19-066-1494/AMC-63

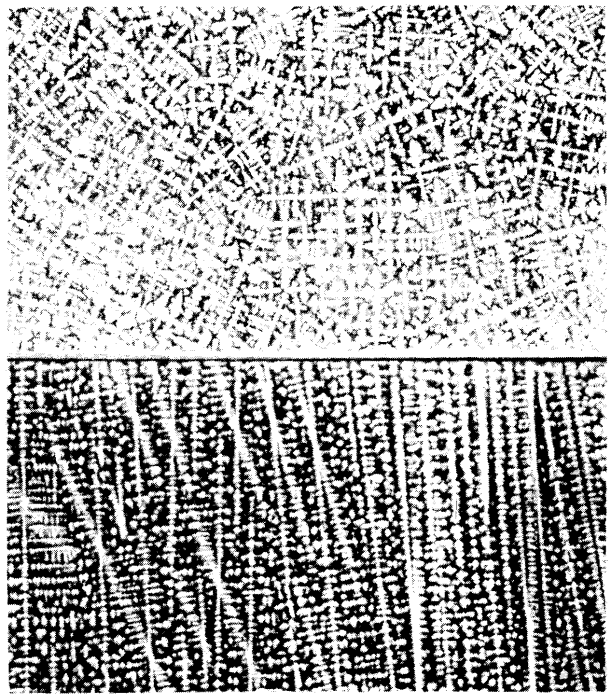


Figure 4. MATCHED SET OF UNIDIRECTIONAL MACROSTRUCTURES. BOTTOM VIEW: VERTICAL MACROSTRUCTURE; TOP VIEW: HORIZONTAL MACROSTRUCTURE.
19-066-1235/AMC-65

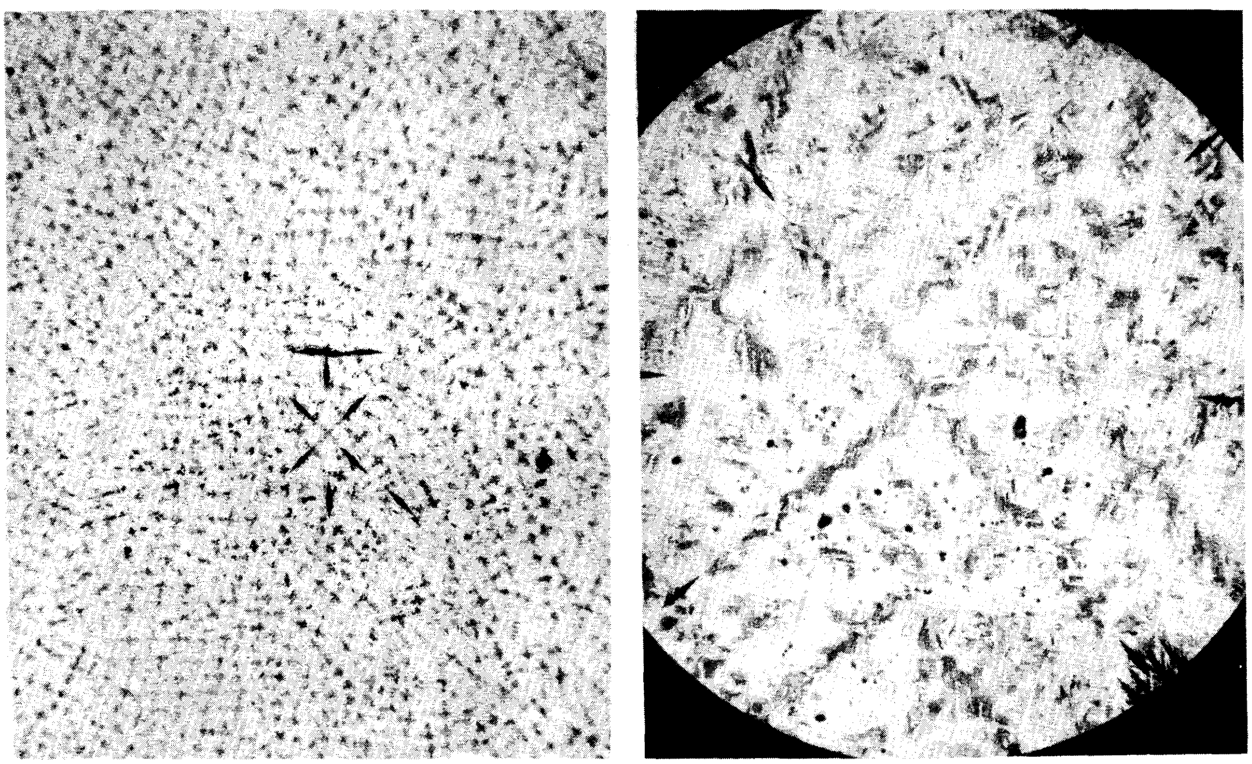


Figure 5. LOCATION OF MICROPROBE SCANS AT 0.125" FROM CHILL (50X) AND 3.44" FROM CHILL (26X)
19-066-262/AMC-64

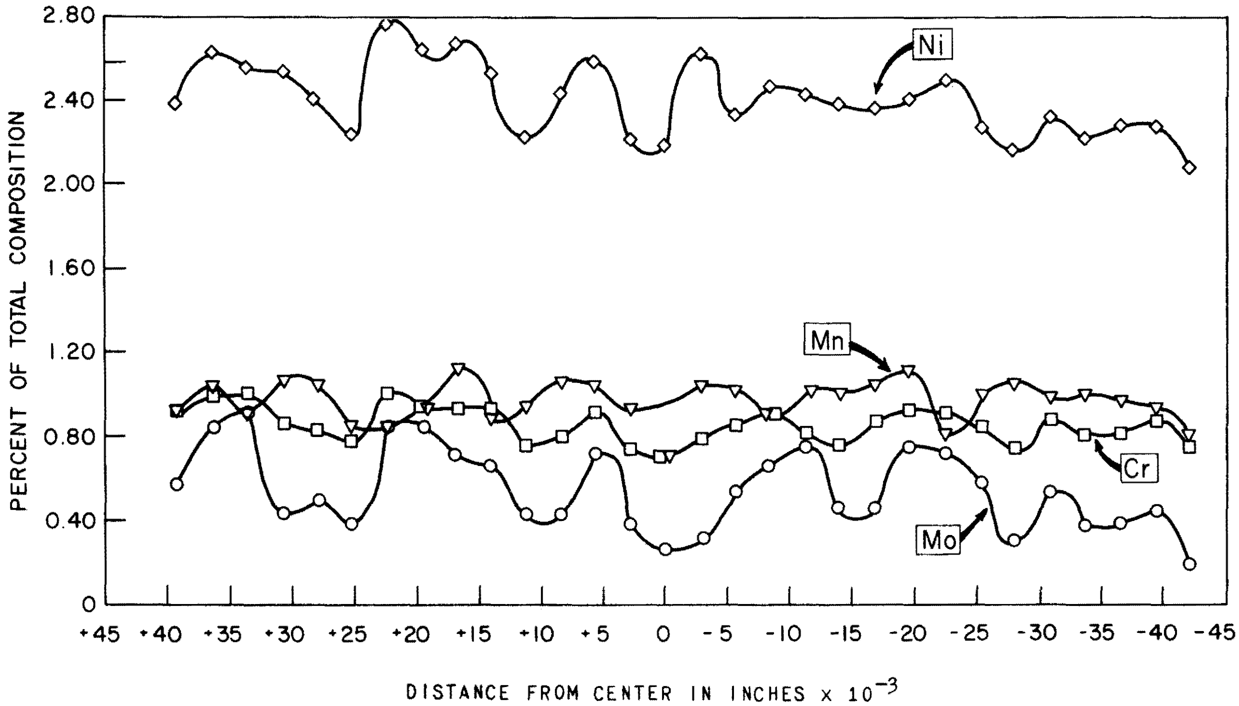


Figure 6. MICROPROBE SCANS FOR MO, NI, MN, AND CR

19-066-1476/AMC-65

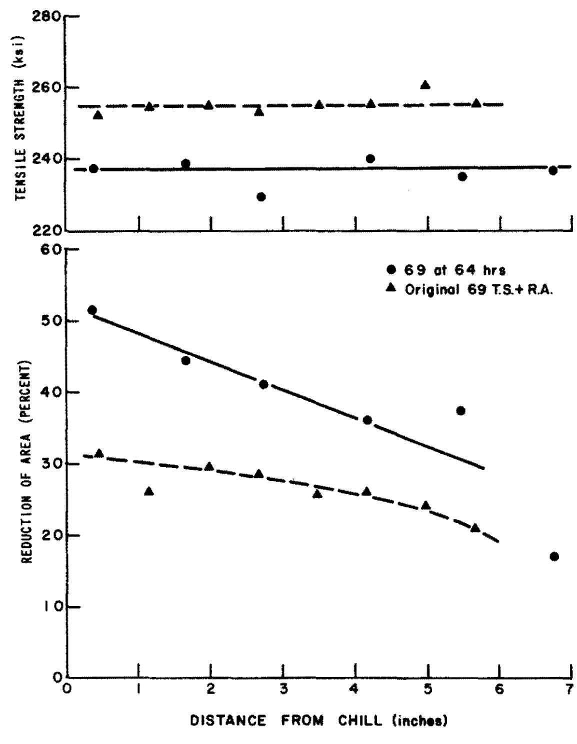


Figure 7. MECHANICAL PROPERTIES OF CASTING 69 BEFORE AND AFTER HIGH TEMPERATURE HOMOGENIZATION

19-066-267/AMC-64

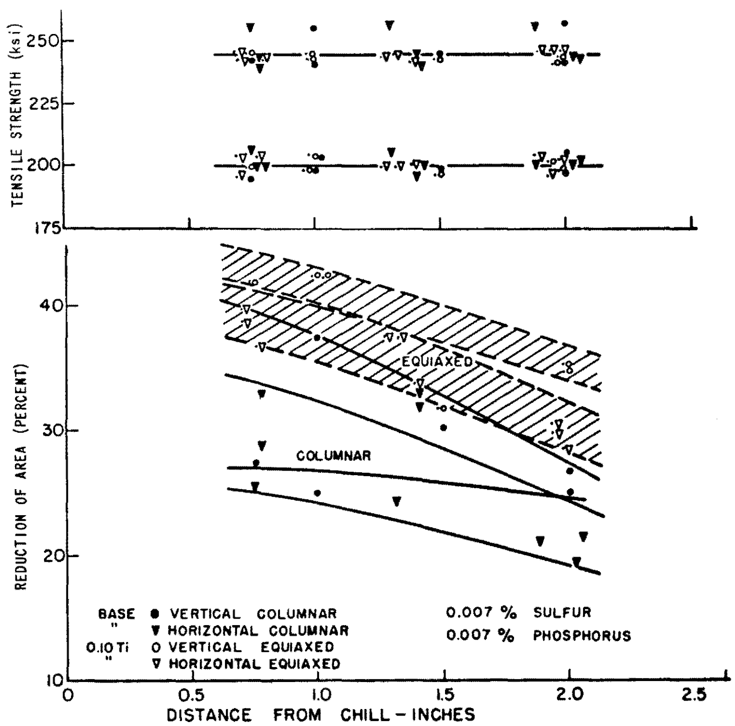
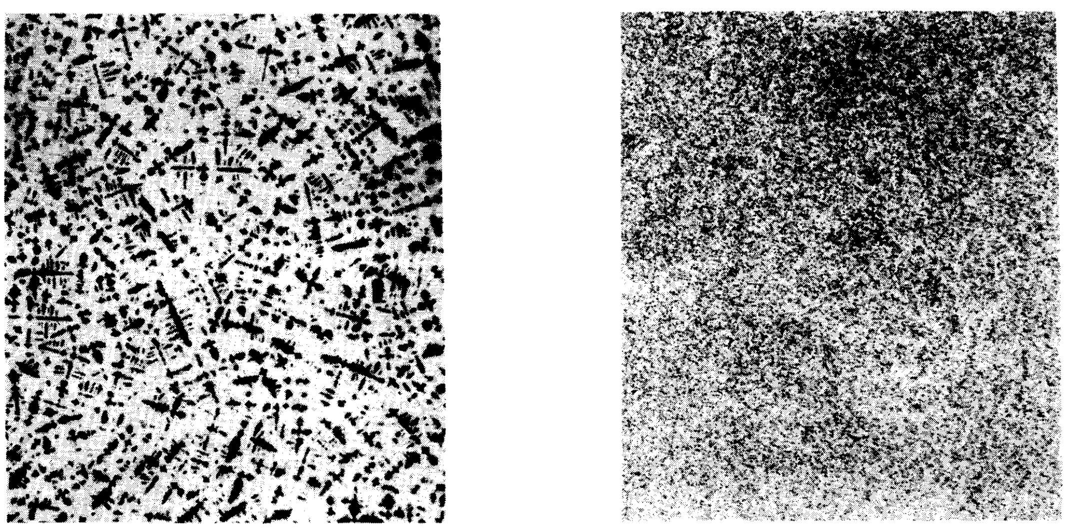


Figure 8. EFFECT OF CAST GRAIN STRUCTURE ON HIGH STRENGTH TENSILE PROPERTIES OF 0.007 SULFUR STEEL (After Wallace, et al)

19-066-1474/AMC-65



a b

Figure 9. STRUCTURE MODIFICATION IN IRON-25 PERCENT NICKEL ALLOY RESULTING FROM UNDERCOOLING. (a) USUAL CAST DENDRITIC STRUCTURE, 12X; (b) STRUCTURE OF SAMPLE UNDERCOOLED 300 C BEFORE SOLIDIFICATION. (Kattamis, Strachan, Flemings)

19-066-1461/AMC-65

DEFORMATION PROCESSING OF METALS

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Introduction

The subject of Deformation Processing of Metals can be divided into seven areas. Area A, Conventional Deformation, consists of studies on forging, rolling, deep drawing, wire drawing, extruding and swaging of reactive and refractory metals and alloys under controlled atmospheric conditions. Area B, High Energy Rate Forming, consists of studies on chemical, electrical, and pneumatic type energy systems, to determine the influence of high energy rate forming on mechanical and physical properties, and formability of high strength alloys, reactive alloys and refractory metals. The deformation mechanisms active in these materials are also included. Area C, Special Deformation Processes, consists of studies on the effect of thermomechanical processing, pre-stressing, atmospheric control, and unique forming methods on mechanical properties and formability of alloy steels, nickel and cobalt base alloys, and refractory and reactive metal alloys. Deformation mechanisms and obtainable geometries are also included. Area D, Special Deformation Effects, consists of studies on the causes and effects of texture hardening and cryogenic strengthening of HCP structured alloys and 300 series stainless steels, respectively. Studies how these affect, influence and control mechanical properties and formability of the susceptible materials are also included. Area E, Composite Fabrication, consists of studies on rolling, machining, and forming of composite structures. The actual forming of a composite structure into a shape such as a hemisphere or a nonsymmetrical structural member requires considerable research in metal removal and forming techniques above and beyond those encountered in actually fabricating the composite cross-section. Area F, Metal Removal Techniques, consists of studies on mechanical, electrical, chemical, and electrochemical means of removing metal. This involves the theoretical aspects of the metal removal mechanisms encountered in all four metal removal techniques, and the effect of the properties of the work material on the activation of these mechanisms. Surface activation studies, prior to metal removal, are also included.

Specific Areas of Coverage

AREA A. Conventional Deformation (forging, rolling, deep drawing, wire drawing, extruding, swaging).

AREA B. High Energy Rate Deformation (chemical, electrical, pneumatic).

AREA C. Special Deformation Processes (thermomechanical, pre-stressing, pre-straining, atmospheric control, shear forming, ultrasonic irradiation,

high pressure fluid forming, solid state deformation bonding, high pressure-high temperature forming, impact and hydrostatic extrusion, fluid-fluid extrusion, hydraulic-pneumatic extrusion.

AREA D. Special Deformation Effects (texturing, cryogenic strengthening, superplasticity).

AREA E. Composite Fabrication (sandwich rolling, machining and forming metal fiber-metal matrix composites).

AREA F. Metal Removal Processes (mechanical, electrical, chemical, electrochemical).

State-of-the-Art

AREA A - Conventional Deformation

Conventional deformation is considered as a separate area inasmuch as the techniques associated with this type of forming have been more or less given a "back seat" in development studies in preference to some of the more exotic deformation techniques, such as high energy rate and high pressure-high temperature forming. However, the bulk of all Army hardware is still processed using these techniques. Much is to be done in improving the efficiency, suitability and versatility of this equipment with regard to forming of the newer high-strength elevated-temperature alloys, as well as the high-tonnage medium-strength alloys. For example, the influence of alloying content, microstructure and heat treatment on the rollability of steel sheet materials for subsequent use as rolled and welded cylinders must be studied. The effect of rolling cycle on steels and titanium alloys, including reduction ratios and temperatures, on subsequent drawability into such items as cartridge cases, pressure containers and end closures is not well defined. The role that mechanical and crystallographic texturing plays in drawability and biaxial stress analysis must be optimized. All of the above effects are markedly controlled by parameters encountered in conventional deformation, such as temperature, processing cycle, reduction ratios and reduction rates.

AREA B - High Energy Rate Deformation

High Energy rate deformation (HERF) offers distinct advantages over conventional deformation techniques for very specific situations. For example, HERF allows one to form sheet materials into complex configurations such as ammunition containers, transmission covers, and hemispherical end closures with a minimum of forming and subsequent metal removal operation. In some instances improvements in mechanical properties are obtained as a result of the high strain rates experienced during deformation. Even in forming certain relatively heavy sections, such as aluminum fin stabilizing rings, steel transmission and engine gears, and aluminum and steel small weapon components, marked materials saving are obtained. The possibility of forming components, such as shaped charge cones, which are not conducive to fabrication, using available mechanical processing techniques, is anticipated. Most promise lies

in the deformation of difficult-to-form alloys, such as the refractory metal alloys and elevated temperature materials, into shapes such as nozzle and barrel liners and hemispherical shapes.

AREA C - Special Deformation Process

Through the use of a number of special deformation techniques, we are able to provide a means to improve upon the properties of existing materials (such as steels) as well as new materials (such as titanium and uranium alloys), as well as increasing the efficiency of forming such materials into Army hardware. The techniques listed under this area represent methods which are specifically applicable to Army needs, such as fabricating high-strength thin-walled tubing for missile cases and recoilless rifles; forming shapes such as cones for shaped charges; reducing material required to form items such as small bore weapon components as well as rocket nozzle liners; improving upon forming techniques for close support weapon components such as mortar bases, clamps, and ammunition components such as projectile bodies and launching piston assemblies.

AREA D - Special Deformation Effects

These effects include mechanical and crystallographic texturing influenced by metallurgical phase relations, crystallographic structure and deformation techniques; and cryogenic strengthening which is based upon the ability of certain materials such as the 300 series stainless steels to exhibit marked increases in room temperature strength when deformed at cryogenic temperatures (-320 F and lower).

Of particular interest to the Army, the texturing of susceptible materials such as the HCP structured beryllium and titanium alloys offers a means of obtaining structures for missile casings and cylindrical components showing strength/density ratio well in excess of 1.5×10^6 inches. Studies are required to determine if other crystallographic structures are susceptible to a degree of texturing which would improve upon the mechanical properties and formability of ordnance materials, such as steels, aluminum alloys and refractory metals. The relationships between texturing and cryogenic strengthening also needs studying to determine how to control and influence these mechanisms.

AREA E - Composite Fabrication

Composite fabrication offers the potential of producing a configuration which takes maximum advantage of the good qualities of the various materials comprising the composite, and minimizing the effects of their unwanted qualities. For example, a high density refractory metal might be used as a cover sheet of a composite to afford corrosion or erosion resistance at elevated temperatures, while a lower density high-strength erosion-susceptible material, such as titanium, might be contained within the refractory metal covers, thus producing a lightweight structure, having a high composite elastic modulus, and being capable of performing satisfactorily at moderately elevated temperatures. Typical Army needs are lined small weapons barrels.

However, many problems are involved in fabricating composites, and especially in forming and machining of the composite structure. Forming of composites into hemispheres for missile nose cones, base plates for mortars or personnel armor applications are typical Army needs. Machining operations can be even more critical than forming since if the forming operation is not completely successful, metal removal techniques might be required to rectify such a situation. Methods must, therefore, be devised to remove the metal without degrading the performance characteristics of the composite.

AREA F - Metal Removal Processes

Probably the most singularly important phase of mechanical processing, with respect to dollar value of material in fabrication, is found in metal removal. Since it is impractical to assume that deformation techniques will advance to such a degree that metals removal techniques will not be necessary, efficient and effective metal removal techniques must be developed and improved upon. The basic metal removal mechanisms involved in the four techniques listed in "Specific Areas of Coverage" require evaluation in order to select the optimum technique for the specific class of ordnance materials, such as refractory metals, steels, super alloys, reactive metals, light alloys, etc. In addition, the optimum procedures for each of the four individual techniques must be established. Since practically all Army hardware requires some degree of metal removal, it is recommended that only specific problems be attacked in addition to conducting basic studies in all phases involved in the mechanisms of metal removal.

Goals, Current and Future Problem Areas

AREA A - Conventional Deformation

Conventional deformation studies are divided into two categories; primary forming, such as rolling, forging and extrusion; and secondary forming, such as deep drawing, swaging, sheet rolling, bending, etc. Reactive alloys and refractory metals necessitate the establishment of new conversion and fabrication procedures operating under inert atmosphere and vacuum conditions to eliminate surface contamination and tearing, to reduce the volume of metals utilized, to improve reduction efficiency, and to promote precision forming.

Problem areas are control of environment during conversion of reactive alloys and refractory metals; extrusion of refractory metals; sheet rolling of refractory metals; forging of reactive alloys and refractory metals. Basic studies on mechanisms of deformation and their effect on mechanical and physical properties; dimensional control and reproducibility; control of decarburization in low alloy steel forgings; effect of forging direction on mechanical properties.

AREA B - High Energy Rate Forming

High energy rate forming includes three categories listed in order of

decreasing forming rate: explosive forming (microseconds), electro-discharge and magnetic field forming (micro- to milliseconds), and mechanical-pneumatic forming (milliseconds).

High velocity deformation involves two phenomena: (1) the influence of strain rate or time on the stress-strain relationship or strain rate effect, and (2) strain wave propagation; these waves becoming significant when the material acceleration is sufficiently high that the inertia forces in the material are of the same magnitude as the internal elastic forces which cause resistance to deformation. Both of these effects, which in many instances are interdependent, must be evaluated in order to determine the implementation, usefulness, and practicality of HERF.

Problem areas are high energy rate forming of high strength steels, reactive alloys, and refractory metals; effect of rate of deformation on mechanical and physical properties of high strength steels, reactive alloys and refractory metals; active deformation mechanisms at high rates and geometries obtainable using high deformation rates; dies stability in explosive forming; effect of strain waves on mechanical properties with minimum plastic deformation; reproducibility of dimensions and mechanical properties; control of parameters in basic material which affect forming; controlling the effect of adiabatic heating upon the mechanical properties of the formed part; control of workpiece temperature and degree of deformation and cooling rate of the formed part.

AREA C - Special Deformation Processes

New and unique deformation techniques have shown usefulness for specialized applications. These techniques include shear spinning, thermomechanical processing, pre-straining or pre-stressing, single point deformation and impact and hydrostatic extrusion. The effects of the type of deformation, implemented by the specific forming techniques, on the mechanical and physical properties of high strength and high alloy steels, nickel and cobalt base alloys, and reactive metal and refractory metal alloys have to be determined. Of equal importance are the deformation mechanisms associated with each forming method and materials and their effects on metal movement and obtainable geometries and configurations.

Pre-straining and thermomechanical treatments, for example, have profound effects on the metallurgical structure, behavior and properties of high strength alloys, notably medium carbon steels and work hardenable alloys. The interrelationship between these deformation techniques and resultant mechanical properties must be quantitatively analyzed to take maximum advantage of the effects of these treatments.

Problem areas are deformation of selected steels by thermomechanical means; elevated temperature, shear forming of reactive alloys and refractory metals; effects of pre-stressing and pre-straining on mechanical properties of high strength alloys; dimensional control with impact extrusion, size limitations of hydrostatic extrusion, effect of hydrostatic extrusion on mechanical properties, requirements of base material for hydrostatic extrusion.

AREA D - Special Deformation Effects

Two interesting areas which potentially could provide us with "breakthroughs" in obtaining marked increases in mechanical properties of certain high strength materials are deformation texturing and deformation at cryogenic temperatures.

Studies on texturing of alpha-beta titanium base alloys have indicated that by properly aligning the basal plane of the alpha-HCP phase, increases in strength of nearly 100% can be obtained. Similar effects are evident in beryllium alloys and other metals and alloys possessing HCP structures. The effects of processing variables, especially deformation, on the degree of texturing and resultant mechanical properties must be systematically determined and evaluated.

Deformation of certain metals, such as the 300 series stainless steels at cryogenic temperatures, results in extensive improvement in mechanical properties. For example, yield strengths have been increased in some cases from 150,000 to over 200,000 psi. Extensive studies in correlating metallurgical transformation, degree of deformation, mechanical properties and formability of these similar metastable materials must be conducted to insure the practicability of utilizing such processes.

Superplasticity has been revealed as a potentially powerful tool for metals deformation. Through controlled phase relationships and changes, extremely high plastic reductions can be obtained at relatively low temperatures in specific types of alloys.

Problem areas are deformation of texture-sensitive materials such as Ti and Be base alloys and effects of processing variables on mechanical and physical properties; deformation at cryogenic temperatures of susceptible metastable stainless steels such as 301 and 304 types and determination of effects of deformation variables on mechanical and physical properties; evaluation of processing variables including degree and temperatures of deformation and thermal cycling on mechanical and physical properties for both the cryogenic and texturing techniques; size and geometry limitations of cryogenic forming; determination of proper phase relationships and morphology for controlling superplasticity.

AREA E- Composite Fabrication

Gross composites are finding enthusiastic acceptance in service applications requiring a combination of properties unobtainable in single structural materials. Laminates, such as newly developed stainless steel clad aluminum sheet, are one type of gross composite. Although processes for producing the laminates in sheet or cylindrical forms are available, these frequently warrant improvement to assure integrity of the bond between adjoining laminae. Fabrication processes to shape and machine sheet laminates are needed. Although adhesive or mechanical methods for joining laminates to other parts are adequate, brazing or welding requires attention. Honeycomb and corrugated core sandwich materials are another important type of gross

composite. Although cover sheets may be attached to the core by adhesives, service at elevated temperatures requires composites bonded by brazing or welding. Development of these latter methods is required for fashioning non-planar panels suited to the configuration and nature of the composite member. Provisions must be made for machining the composite to achieve the proper dimensions, to accommodate fittings, and to permit joining to contiguous parts of the weapons structure. Methods presently required to machine the composite without distorting the thin metal or rupturing the bond between core and cover sheet are unsuited to production efficiency. Composites consisting of metal fibers and metal matrices are in need of study and should receive increased emphasis.

Problem areas include cover sheet and foil rolling of advanced metals; forming sheet laminates; machining sheet laminates; interlaminar bonding; joining of laminates; bonding of sandwich core composites; fabrication of foams; development of metal fiber-metal matrix composites; effect of direction of fibers in matrix on mechanical properties; development of techniques to introduce ceramic fibers into a metal matrix.

AREA F - Metal Removal Processes

In the past fifteen years there has been much effort expended in the study of chip formation. There is some disagreement between many highly qualified investigators as to the mechanisms involved, but one of the most recent approaches, based on principles discovered in solid state physics, explains much of the phenomena observed in the machining process.

In the past, most research has been conducted utilizing steel because of its extensive use as an engineer material. Because of its heterogeneous nature, many impurities and unusual alloy combinations, the results of the study of chip formation with this material are strictly empirical. Studies of chip formation in pure materials such as copper and aluminum show promise of results that may be applied to all other materials.

The mechanism of atmospheric or chemical effects on machining properties is not well understood. Seemingly contradictory reports on effects of cutting fluids have been published. The possibility of using a material's natural internal energy properties to assist in metal removal appears promising. The effects of the properties of surface and interfaces in metal cutting and chip formation require study. A greater knowledge of thermodynamics of surfaces is required for understanding of the processes of chip formation.

The application of results from metal cutting research often requires considerable time as evidenced by the use of carbide tool materials which were developed initially in the later 1920's, but were not generally accepted until the years after World War II. The development and utilization of ceramic nonstrategic cutting tools are at present pursuing a similar period of transition. Considerable study is needed to develop cutting tools capable of machining high temperature, high hardness materials which have been recently developed and which cannot now be machined economically.

Much work is needed to realize to their fullest capability the advantages of the best features of abrasive machining alone, or in combination with edge tools. The development of improved materials and methods for the application of abrasive machining could very well result in an economic removal of materials that are now machined at high cost and low removal rates.

Methods for the application of heat to the cutting area without damaging the workpiece are needed in processing of the difficult-to-form materials. The development of economical methods of localized heating in the cutting zone could result in rapid metal removal of materials which are, at present, considered difficult if not impossible to machine. There are several unconventional methods of metal removal which need development to a state where they will be competitive with the conventional methods. They are:

1. Softening, melting or evaporation by thermal effect.
2. Dissolution by chemical effect.
3. Electrochemical.
4. Erosion.

There is a definite need to evaluate these methods for applications in Army requirements. When a particular method appears to be better than conventional methods with respect to quality or rate of metal removal, they should be seriously investigated.

One process that shows promise is the ion-beam as an extension of the electron beam machining method. The plasma jet, with new or improved methods of concentration and control of release energy, appears promising. The development of substantially higher energy levels to be applied to "ultrasonic machining" would enable the area of usefulness of this method to be greatly increased and the possibility of using the natural internal energy of a work material is a subject of intensive study.

Summary

Most weapon systems are composed of at least one component which requires either metal forming or metal removal operations during fabrication. The forming or deformation of the metal usually affects its mechanical and physical properties, and conversely these same properties greatly affect the formability of the metal into a desired configuration. This same set of effects is also applicable to metal removal operations, but usually to a lesser degree.

More specifically, the formability of a metal and the effects of deformation on the properties of a metal are influenced by such parameters as work hardening exponent, crystallographic structures, ductility, hardness, and toughness. Of course, other parameters enter into the picture, but they can usually be translated in terms of the specific properties listed above. However, when discussing metal removal techniques, the technique itself determines what specific properties are most influential in affecting removal efficiency. For example, removal by mechanical techniques such as "normal tool

machining" is mostly affected by the shear properties and hardness of the metal in conjunction with many of the formability properties mentioned above. In contrast, "chemical milling" is highly dependent upon the reactivity or passivity of metal, or more simply stated, its corrosion resistance. Still further, electrical discharge machining is affected by the conductivity, melting point and dielectric strength of the metal, while in contrast, shear strength, hardness and strain hardening exponent have practically no effect.

Development of metals deformation or metals removal processes is the obvious next step after the development of a metal or alloy. In order to take full advantage of the mechanical and physical properties imparted to a metal as a result of development studies, means of converting the basic material into a shape suitable for Army applications are essential. These conversion operations must not only be conducted in such a manner that preserves the desired properties of the basic material in the formed shape, but often times necessitates an improvement in such properties in the prescribed shape.

In order to prevent property degradation or if possible, promote property improvement during deformation, the deformation mechanisms peculiar to the metal must be determined and influenced where beneficial. Similar studies are necessary with metal removal techniques to improve old or create new ones.

The needs of the Army dictate that such studies be specifically oriented towards certain types of metals, such as steels, aluminum alloys, magnesium alloys, titanium and refractory metals, configurations such as hemispheres, cylinders and those shapes associated with structural members, and composites such as metal fiber-metal matrix combinations.

Basic studies in physical metallurgy, fracture mechanics and physical chemistry are necessary to determine the extent, control and effect of the many factors influencing deformation and metals removal.

For example, in the discipline of physical metallurgy, the effect of alloy content and crystallographic structure on deformation mechanisms such as slip and twinning and their interaction with dislocations must be established and controlled. In fracture mechanics, similar parameter effects on crack stability and crack propagation in high strength alloys, such as titanium alloys and steels, must be analyzed and influenced. In physical chemistry, the effect of surface activating agents, such as sulfur and oxygen on surface shear properties of metals, must be analyzed to improve upon metal removal techniques.

METALS JOINING

Donald C. Buffum
Chief, Metals Joining Branch
Materials Technology Division, AMRA

During the past few years, materials and joining processes have been developed at an impressive rate. However, little has been done to advance the

theory of joining of materials and to acquire basic knowledge of the metallurgical phenomena peculiar to it. Usually, the welding engineer does not learn of the problems facing industry until the design of a given item is complete and trouble develops in production.

As a result, we find ourselves faced with two major problems. First, we have a lack of basic knowledge of the metallurgy which is peculiar to joining and second, an ever-increasing number of immediate problems that need solving so that production can progress. Under present day conditions, it is not practical to stop the second type of program until we better understand the fundamentals of the processes we employ. The logical solution is to carry on a dual program aimed at a balance between finding the solution to present day problems and investigating the metallurgical phenomena that are peculiar to joining.

If we can conceive such a program, the Army will be able to construct its equipment using joining techniques that will be satisfactory if not optimum, and we also will be able to develop the knowledge that, in time, will enable us to provide the Army with methods of fabrication that will use the materials and processes available with the greatest efficiency.

The field of metals joining can be broken into five main areas in which research is needed, these are: composition; solidification; heating cycles; prior- and post-joining heat treatment; atmosphere and environment.

Composition

In order to increase the mobility of the Army, effort is being expended to lighten Army materiel. This is being accomplished by the use of higher strength steels in thinner sections and by the use of lightweight metals, such as the aluminum alloys and the titanium alloys. In addition, the operational temperatures on many applications are increasing and it is found necessary to utilize high temperature materials, such as the refractory metals for many component parts. In almost every case alloys are developed without consideration for their weldability, and the problem given to the welding engineer is to join these alloys and produce joints that are 100% efficient from the mechanical property standpoint. To overcome the problems that arise, work is needed to determine the effects of composition on weldability and at the same time develop procedures for joining existing alloys, not only to themselves but also to other metals.

Procedures have to be developed to join the maraging steels and the high-strength modifications of SAE 4340 steels. Here we have to reduce flaws and the tendency to crack while striving for 100% joint efficiency. The lighter weight alloys such as magnesium alloys, titanium alloys, and aluminum alloys have been vastly improved during the past few years and effort is needed to join these materials to themselves and to other structural metals. There are such problems as joining cast, wrought and forged aluminum alloys to each other, joining aluminum alloys to wear-resistant alloys and to steels, and eliminating or reducing the flaws produced in the joining of titanium alloys.

In most joining methods used by the Army, it is necessary to have filler metals. The suitability of the joint produced quite often depends upon using the right metal or alloy as filler wire. The production of a successful joint also depends upon the control of many variables that concern the wire. These variables include its surface condition, size, shape, cleanliness, alloy composition, gas content, moisture content in the case of coated wire, and the wire coatings themselves. Effort is needed not only to determine what wire is best for a given parent metal but also to determine the tolerance that can exist in the variables without detrimental effect upon the welded joint.

Further, the use of the best alloys for a given application has brought about the need to join dissimilar metals and to join composites of metals. It is easy for one to picture the added problems that such combinations can introduce. Not the least is the condition that exists when a metal has been given a protective coating and must be joined without losing the effect of that protection.

The refractory metals - tungsten, tantalum, columbium and molybdenum - are finding increased use in Army components. These metals must quite often be joined to themselves, to each other, and to other structural materials. In the latter case, because of their difference in density and in melting point, problems result which are in great need of research for solving. One of the most pressing needs for the utility of refractory metals in the Army is the requirement for a means of fusion welding without overly complicated, elaborate and restrictive precautionary methods of preventing contamination. Proposals involving thermochemical methods, protective fluxes, or other ingenious means to provide sound welds should be encouraged.

Brazing is a phase of joining that, because of new alloys and new structural materials being used by the Army, is finding new and more widespread applications. Knowledge of the inter-reaction of brazing materials with the parent metal is greatly needed. Further, there is a need for the development of new brazing materials that are compatible with the new materials. The refractory metals are one group of materials that come under this latter category on which work is necessary at the present time.

Solidification

The rate and mechanism by which the weld bead solidifies will have a large effect upon its metallurgical properties. Although one cannot exercise the same control in welding that is possible in casting, there are variables which can be controlled and must be studied. Besides solidification characteristics related to process differences, these variables include heat input rates and heat flow patterns affecting solidification and transformation phenomena.

With the rapid development of advanced welding techniques, it is possible to utilize different methods which vary the heat input. However, the effects of varying the heat input are only roughly known. Research is needed to determine the effect of various heat sources and thermal transfer efficiencies upon

the metallurgical structure of weld beads. These studies must take into consideration the differences in techniques needed for material of various thicknesses and materials of different compositions. Then a further step is necessary to correlate the heat input rate or rates thus determined with compatibility of control in commercial welding equipment.

Joint design, joint geometry, jigging, fixturing and composition, all play a role in controlling the rate at which the weld bead will cool from the molten state to room temperature. It is necessary to know over what range this cooling rate must be controlled to obtain the desired cycles to produce joints of optimum metallurgical quality.

It should be understood that in the process of welding the rates of heating and cooling are not necessarily linear, and it is very important to know the shape of the heating and cooling curve that will produce the best results.

Another phase of welding solidification that requires study is the effect of variables that can affect grain refinement. Two of these are vibration and crystal nucleation control. It is feasible that a given vibrating motion could be introduced into the solidifying weld bead that would control the nucleation and growth of grains. In addition, it should be possible to add elements to the solidifying weld bead that would cause an improved pattern of nucleation. Work is needed on both ferrous and nonferrous metals to determine techniques that can be used to improve joint efficiency by this method.

Much research is being done on casting and the researcher should keep abreast of the developments in this area, to determine ways of adapting their improvements to the joining process.

Heating Cycle

In the preceding section on solidification, it was mentioned that the control of heating cycles should be studied in connection with controlling the structure produced in weld beads. It is also proposed that research should be extended to study heating cycle for control of structures produced in the heat-affected zone of the joint area. Quite often we find that in a welded structure the part of the weld area that is most detrimentally affected is that region between the weld bead and the unaffected parent metal. The range of temperatures through which this zone passes is related to the time-temperature-transformation space between the liquidus and room temperature on conventional isothermal transformation diagrams. Under given conditions, it is possible to produce almost any metallurgical structure to which an alloy can be heat treated. Exploratory research is necessary to determine the amount of control that can be exercised with the variables in the welding process that are at our disposal. Studies of the structures produced in the heat-affected zone must be made along with determination of the effects of the welding variables upon the amount and distribution of these structures. Steps must be taken to reduce or eliminate those structures which are most detrimental.

Prior- and Post-Joining Thermal Treatment

This area employs the other metallurgical tool, heat treatment, which is most common to metallurgical practice. However, in this instance we find that the material being heat treated is inhomogeneous not only compositionally but also structurally. Further, the time involved will preclude the development of equilibrium conditions.

Although the fundamentals of heat treatment have been quite extensively developed, the presence of the above conditions necessitates the development of theories that are peculiar to welding needs. Exploratory research is needed to determine not only what types of prior- and post-thermal treatments are necessary, but also means of applying these heat treatments to welded structures common to Army materiel.

Amother prime objective of pre- and post-joining thermal treatment is to reduce the tendency for cracking in a welded structure. Although this type of treatment has been helpful in alleviating such tendencies, research is still needed to determine the causes and how to eliminate the cracking problem.

Atmosphere and Environment

The atmosphere and/or environment in which a joint is fabricated can well determine the soundness and efficiency of the joint produced. In welding, it will have an effect on the production of nonmetallic flaws as well as on porosity and interstitial gases in the joint area. Hydrogen has long been a troublesome element in metals joining and its presence as a gas or as a compound in water or oil vapor is an area that is in need of further study. Also, the presence of small quantities of active gases in protective atmospheres of inert gas or in vacuums can lead to difficulties. Investigations are necessary to determine qualitatively and quantitatively the effects of the various gases as contaminants upon the joint area.

In the fabrication of brazed and soldered joints, atmosphere plays an important role in the wetting of the parent metal by the braze metal, in the contamination that can develop within the joint area, and in the capillary flow of braze metal necessary for a sound joint. Studies are needed to determine the effect of various protective atmospheres and the effect of joining in vacuum upon the metallurgical factors mentioned above. Although effort is needed on several materials, presently the greatest need appears to be required on the refractory metals.

Unless research is carried out to correlate the joining variables with the metallurgical structures produced in the joint, joining will remain an art subject to the skills and experience of the operator.

METALLURGICAL ASPECTS OF FRACTURE

Frank R. Larson
Chief, Metals Laboratory
Materials Engineering Division, AMRA

One of the long standing problems for the Army has been premature fracturing of service components. From our practical experience with these failures we know that many times these events could have been avoided with proper metallurgical control. Much of our research and development program has been directed towards establishing the influence of metallurgical variables upon the fracturing characteristics of metals.

During various eras of investigation, research has been focussed on the elementary fracture behavior patterns as a function of such things as microstructure, chemical analysis, cleanliness, directionality and more recently high strength level.

As research and practical experience in the area of fracture advances, we find many of our basic ideas need modification to fit the current information. One of the most recent developments in this area is that of the effect of phosphorus and sulfur on the impact strength of 4340 steel. In the past it was not unusual to have phosphorus plus sulfur levels of 0.030% maximum each or higher. A recent investigation at AMRA has shown that air-melted 4340 can be easily obtained with a combined phosphorus plus sulfur level of less than 0.025%. Furthermore, our investigations have shown that these lower phosphorus plus sulfur air-melted steels have markedly superior resistance to fracture. Hence, an industrial technology advance in reducing the phosphorus plus sulfur levels in 4340 steel has improved the quality of our components, in that steel used for their fabrication will have a far greater resistance to fracture even at a higher strength level.

The examples cited are only to illustrate some of the elementary aspects of metallurgical progress in improving the fracture resistance of metals. Of course, there are many other pressing problems in this area. For example, we need to know more about the effect of microstructure on fracturing characteristics of steel, particularly at high strength levels. Recent experience has shown us that steel normally thought to be resistant to temper embrittlement can be severely embrittled when subjected to abusive heat treatment.

Another area of concern is the effect of microstructure on the fatigue, fretting, corrosion, and a combination of these mechanisms. Rarely has a service fracture occurred by a single one of the above modes. Usually, components are degraded by several environmental conditions. The relationship between fatigue and microstructure is only partly resolved. Considerably more research is needed. We plan to devote some of our efforts to this area. In conjunction with this aspect, very little is known about the effects of microstructure on fretting and corrosion. Part of our program will be directed to this problem.

Very recently, startling advances have been made in the area of fracture mechanics. We intend to exploit these advances by utilizing these theories to more thoroughly investigate the microstructural influences on the crack initiation and propagation rates in metallic materials.

It appears that much of the conflicting results in metallurgical studies in the area of fracture have been due to our inability to separate the initiation and propagation stages of fracture. We now have both analytical and experimental techniques for doing this. The electric potential technique, which was developed at AMRA for measuring the initiation and propagation of cracks during fracture, is an excellent experimental tool to study these phenomena. It has been known for some time that various factors influence the initiation of cracks and in some cases this overshadows the propagation stage. Thus, these experimental results are not applicable to the service case where the cracks are already present and vice versa for the case where the experimental work was strongly influenced by crack propagation stages.

Therefore, with the new instruments and analytical techniques, certain key areas associated with fracture should be reinvestigated. One particular type of fracture which has caused several service failures is that of hydrogen embrittlement. The various stages of crack initiation and propagation for this type of fracture are known to be strongly dependent upon metallurgical factors. Some of the prior research in this area has shown that the initiation and propagation rates can be quite different depending upon the metallurgical conditions of the base material and the amount of hydrogen present. Recent results in the area of stress corrosion fracture have been a cause for great concern. Investigation at the Naval Research Laboratory has shown that certain titanium alloys are strongly resistant to crack initiation, yet very susceptible to crack propagation. Thus if a crack is present prior to service, catastrophic failure will be most probable. On the other hand, if we have no cracks present, the structure will probably behave satisfactorily.

It can be readily seen with these new instruments and analytical techniques that much of our experimental and analytical work thereof needs to be reexamined. The area of fracture probably occupies one of the greatest interests and it is a major concern throughout industry and Government research.

NONDESTRUCTIVE TESTING

Otto R. Gericke
Chief, Applied Physics Branch
Materials Engineering Division, AMRA

Test methods used for nondestructive inspection of Army materiel cover many areas of technology such as radiography, ultrasonics, and electromagnetic testing, to name only a few. Since no single method has as yet been found which will detect all types of defects encountered in engineering materials, the search for additional new test techniques has to be continued and physical phenomena through basic research have to be examined for their potential

applicability to nondestructive testing. Neutron radiography, nuclear resonance, and infrared testing are examples of recent additions to the ever-growing spectrum of nondestructive test methods. Because of the increasing complexity of Army weapon systems and the more stringent requirements placed upon materials, it is also necessary to improve existing nondestructive testing techniques and to simplify interpretation procedures.

Nondestructive inspection techniques can be divided into two major categories. One group of tests utilizes electromagnetic energy as the probing medium, the other elastic waves. Visible inspection is the oldest nondestructive test method falling into the first category, and ringing a specimen with a sharp hammer blow is the earliest procedure based on elastic vibrations.

This breakdown into two major fields shall be followed for the discussion of future Army requirements in the area of nondestructive testing.

At this low frequency end of the electromagnetic spectrum, that is, from approximately 1 cps to 100 kcps, eddy current test methods are gaining importance for the rapid inspection of metal parts. Presently, these test procedures are mostly based on an empirical approach. To establish more quantitative procedures, a considerable amount of theoretical work will be needed so that various test parameters can be more clearly identified and isolated. Test frequency, eddy current amplitude and phase, and penetration depth have to be studied individually to achieve better correlation of test results with the various mechanical properties and conditions of test specimens.

Moving up in frequency in the electromagnetic spectrum one encounters next radio frequency and microwaves which can be applied to the inspection of nonmetallic items such as plastics and ceramics. The interest in these test procedures can be expected to increase as nonmetallic substances become more important as engineering materials. Precise techniques for measuring attenuation and phase shift will have to be developed to enable the detection of differences in specimen composition and structure.

Going up further in frequency, one enters the infrared portion of the electromagnetic spectrum. Infrared or thermal test methods show considerable promise as new nondestructive testing tools. The infrared inspection of bond integrity is one area which is under investigation. Figure 1 shows a cross section of a simplified version of a rocket motor case which exhibits two types of bond defects. Figure 2 shows the infrared irradiation and detection system used to detect these defects. The next step that is required to perfect infrared test methods is the development of imaging devices which will produce visible planviews of thermal conditions of specimen surfaces.

X rays and gamma rays follow next in the electromagnetic spectrum and one might also list neutrons here which are also beginning to be used as penetrating radiation. Neutron radiography shows great promise to serve an effective inspection method in such cases where metallic and nonmetallic materials are combined into a single structure. Considerable work is still required, however, to solve the various technological problems of neutron radiography. Photographic film with its unexcelled amplification and energy integration

characteristics is still the most popular detector for penetrating radiation. But, electronic image conversion tubes have successfully been developed for X rays. Future work should aim at increasing the size of such tubes or at replacing them with solid state image conversion panels.

The second category of nondestructive tests employs elastic vibrations, is generally referred to as sonic and as ultrasonic inspection, and is a rapidly advancing technology.

Sonic testing includes excitation and analysis of the natural vibration frequencies of a test specimen. Commercial equipment for this type of test is still lacking and it would be desirable if someone would design and manufacture instruments that can be used for this purpose.

In the ultrasonic area progress is made in various directions. The simultaneous use of more than one test frequency as shown in Figure 3, which illustrates a dual-frequency echo signal, promises to facilitate the interpretation of test results. So does the newly developed technique of ultrasonic spectroscopy which permits the differentiation of metallic microstructures as illustrated by the spectra in Figure 4 and the differentiation of defect configurations as shown in Figure 5 for defects having various orientations with respect to the specimen surface. Additional research work will be needed to develop the full potential of ultrasonic spectroscopy.

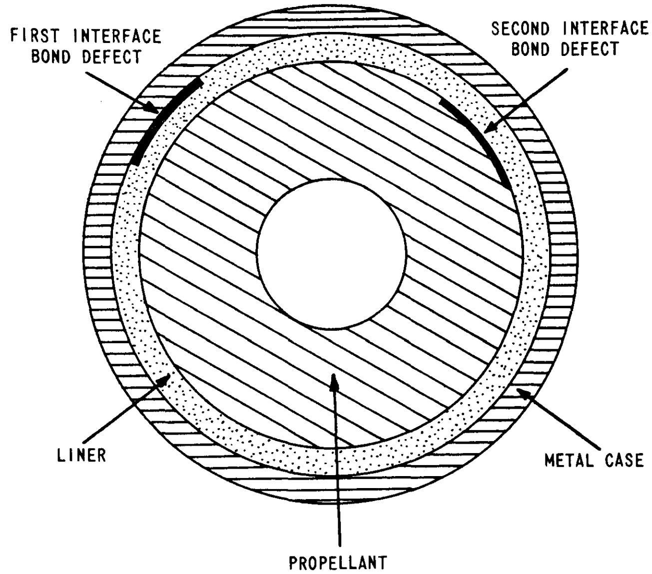

Figure I. CROSS SECTION OF CYLINDRICAL MISSILE MOTOR CASE SHOWING SCHEMATICALLY THE TWO TYPES OF BOND DEFECTS WHICH CAN OCCUR
19-066-36/AMC-63

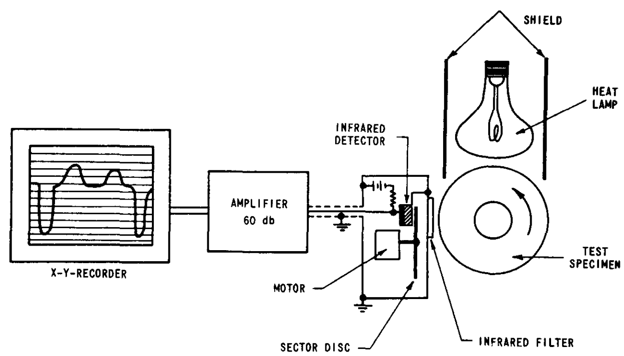

Figure 2. COMPONENTS OF INFRARED BOND INSPECTION EQUIPMENT USED BY AMRA
19-066-37/AMC-63

Another area of ultrasonic testing which is beginning to receive more attention is ultrasonic imaging. Various approaches are presently being studied to determine which image conversion technique will provide the best results. The ultimate goal should be the development of a solid state panel which converts the ultrasonic image into a visible image and at the same time provides amplification.

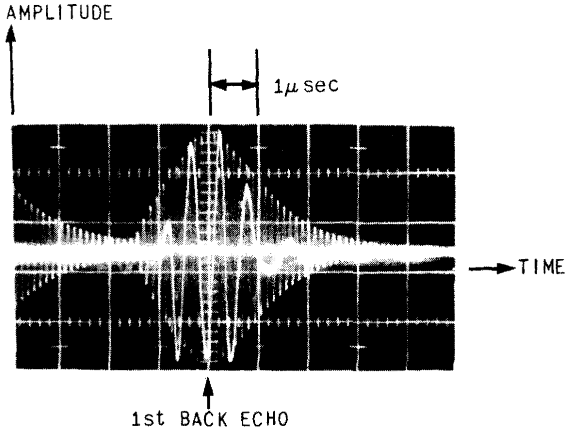

Figure 3. ULTRASONIC DUAL FREQUENCY TESTING

19-066-1394/AMC-63

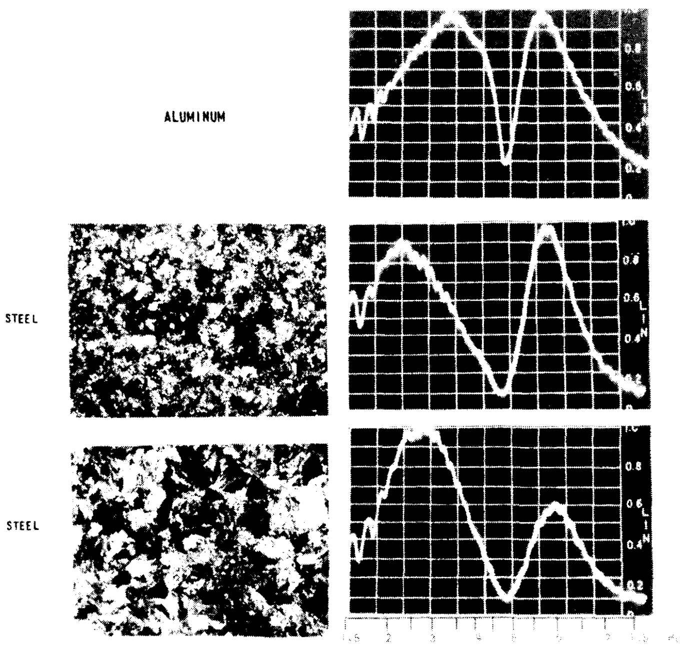

Figure 4. ULTRASONIC BACK ECHO SPECTRA OBTAINED FROM TEST PLATES MADE OF LOW LOSS MATERIAL (ALUMINUM) AND STEELS HAVING DIFFERENT MICROSTRUCTURES

19-066-2059/AMC-64

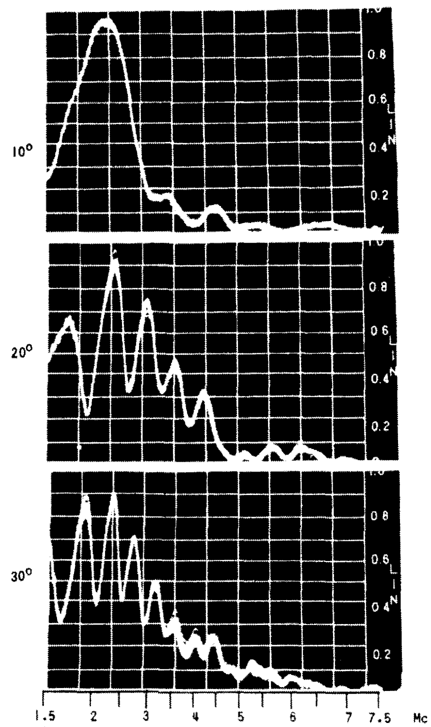

Figure 5. ULTRASONIC ECHO SPECTRA OBTAINED FROM PLANE DISCONTINUITIES ORIENTED AT VARIOUS ANGLES TO THE TEST SURFACE

19-066-2061/AMC-64

Finally, an area of nondestructive testing shall be mentioned which up to now has been greatly neglected. This is the so-called multiple procedure method in which various test principles are combined into a single inspection system. While various tests are often subsequently applied to an item to be inspected, systems which provide a simultaneous read-out are hardly known. Work aiming in this direction is considered very important and might offer great advantages over present-day procedures.

SPECIFICATION CONSIDERATIONS

T. E. Dunn, Jr.
Chief, Materials Standardization Office
U. S. Army Materials Research Agency

Many years ago, I lived in a town where one of our leading citizens was Bill Perry, P.D.F., the Ladder King. Since I was unfamiliar with the initials after his name, I overcame my temerity one day and asked their meaning. Bill replied that when a man reached pre-eminence in his chosen field he generally was entitled to place initials after his name. Bill had served his apprenticeship under his father, so a Ph.D. was not for him. However, he said that his father had never addressed him by any other name than "his damn fool" so he felt that he was fully entitled to the P.D.F., "Papa's Damn Fool".

There is a casual relationship to my story and the work our section does in AMRA. We are responsible for the Department of the Army materials standardization program for structural materials, lubricants, test methods and related processes as shown in the following listing. For some time, I thought that the

STANDARDIZATION MANAGEMENT RESPONSIBILITY

FSC No.	Title	FSC No. or Area	Title
5330	Packing and Gasket Materials	9525	Wire, Nonelectric, Nonferrous
5345	Discs and Stones, Abrasive	9530	Bars and Rods, Nonferrous
5350	Abrasive Materials	9535	Plate, Sheet and Strip, Nonferrous
8010	Paints, Dopes, Varnishes	9540	Structural Shapes, Nonferrous
8030	Preservative and Sealing Compounds	9545	Plate, Sheet and Strip, Foil and Wire, Precious Metal
8040	Adhesives	9630	Additive Metal Materials and Master Alloys
9130	Liquid Propellants and Fuels (Petro Base)	9640	Iron and Steel Primary and Semi-Finished Products
9140	Fuel Oils	9650	Nonferrous Refinery and Intermediate Forms
9150	Oils and Greases (Cutting, Lubricating and Hydraulic)	THJM	Thermal Joining of Metals
9320	Rubber Fabricated Materials	MECA	Metal Castings
9330	Plastic Fabricated Materials	FORG	Metal Forgings
9505	Wire, Nonelectric, Iron and Steel	MFFP	Metal Finishes and Finishing Processes and Procedures
9510	Bars and Rods, Iron and Steel		
9515	Plate Sheet and Strip, Iron and Steel		
9520	Structural Shapes, Iron and Steel		

Figure 1

product of our Office was defined by two words "damn specification" and that I should be entitled at least to append a D.S.D. after my name. However, I assure you that I would forego this title and settle for the one word definition "specification". Perhaps if I explain the basic approach that our office takes in the development and preparation of specifications, I may further the cause.

We prepare both Federal and Military specifications and we have established a definite line of demarcation between these two series, with commercial material in one series and material with added requirements and restrictive testing in the other series.

Since the Federal series is used by all the Government services, we use this series for the normal production capability of the suppliers, that is, so-called commercial material. In the preparation of new specifications for commercial materials we try to adhere to the requirements which represent the norms for the product, and in the revision of the older specifications, which our Office is now conducting on a five-year basis, we try to eliminate extra requirements that may have crept in during previous revisions or in the original preparation.

At the present time we are advancing a step further in the overall standardization of commercial materials and test methods. We are preparing, and in some cases have already prepared and made preliminary recommendations, studies in the areas of steel wrought products, rubber testing methods, adhesive testing methods, and metals testing methods, aimed at elimination of Federal documents and the use of those of the ASTM where similarities exist. We believe that these actions, if successfully consummated, will be a big stride forward in national and international standardization and may even help to drop that little word to which I object.

In the military series, because of logistic demands, our specification requirements do become more stringent. In most cases our engineering determinations have demanded a better product than commercially obtainable and our specifications must reflect these demands. The accumulated data which is presented to us for translations into a specification generally covers the gamut of properties for the material. It is our responsibility to weigh the importance of these properties as they affect the anticipated intended use of the material. It would be very simple for us to merely establish an allowable or specification minimum requirement for the material from the data, but such a practice would result in excessive costs or perhaps might not give us the reliability required in the end product.

As an example, in the development of specifications one basic elemental decision must be made on protection or resistance of the material to penetration. The best method of determining this is to shoot at it, so our armor specifications all contain a ballistic requirement. However, this type of testing is destructive, costly, and time-consuming. We try to determine those properties which contribute to the materials protection ability such as hardness or toughness and relate a value for these tests, a specification minimum or design allowable to the ballistic requirement. By so doing we may reduce our ballistic testing to a minimum and use a cheaper and less time-consuming

testing method to check the quality of the material. Requirements, which though interesting from a data viewpoint but not a requirement of the use of the material, are not included in the specification.

As an example of the failure to make a good determination of requirements from intended or potential usage, I might cite a very sophisticated specification for stainless steel pipe which contained 17 requirements including chemistry, mechanical properties, stress corrosion susceptibility, flaring, nonmetallic inclusions, and hydrostatic pressure. Testing for these requirements was on a 100% basis on the material in the as-received condition. Pipe procured to this document passed every requirement of the specification, but, when placed in service at pressures below the testing pressure, developed leaks. Basically, consideration had not been given to how this pipe was to be used in service. In using the pipe, bends had to be made to fit the structural configuration within which the pipe was run. This material was susceptible to stress corrosion after cold working, hence the resulting leakage. The inclusion of a requirement to cover this condition was the paramount one for this material in its normal usage.

I hope that in this short talk I have been able to show that we do have basic concepts for the development of specifications which are keyed to the best interests of the Department of the Army and the supplier and are not merely written to bedevil your productive facilities.